Peter Donaldson

Hybrid Electric Drives and Fuel Cells

Potentially, hybrid powerplants offer comparable benefits and more to armoured vehicles.
While fuel efficiency has, historically at least, not been high on the list of essential attributes for an armoured vehicle, it does increase range and/or endurance for a given fuel load, improve payload, protection or firepower for a given all-up weight and generally reduce the overall logistic burden of a fleet.

The FC 250 fuel-cell system has a nominal output of 250W, giving it a daily charging capacity of 6kW hours. It can power equipment on large military vehicles or do duty as a field generator. It has been designed especially for military applications including test scenarios in which data on new defence systems need to be collected and evaluated in the field. (Photo: SFC Energy)

Hybrid electric drive may play an important part in the future of military vehicles, but the respective cancellation and scaling down of the US FCS and UK FRES programmes, the 2008 cancellation of Sweden's SEP procurement, and the scramble to meet UORs for protected vehicles have conspired to push its entry into service further into the future.

However, when the contenders for the US Ground Combat Vehicle (GCV) were announced in January 2011, they included an entry from the BAE Systems/Northrop Grumman team with a hybrid electric powertrain that includes Qinetiq's E-X-DRIVE system. This could be seen as something of a gamble because none of the contenders for the Joint Light Tactical Vehicle (JLTV) programme that included hybrid electric drive made the cut, because the US Army reportedly believes that the technology is not yet sufficiently mature for that vehicle's timeline. However, the GCV's later planned entry into service could make the difference. Beyond this, the story of hybrid electric drives in military ground vehicles has been one of technology development and demonstration programmes. There is, something inexorable about the global pressure to adopt a technology that promises to save fuel, improve performance, and survivability while meeting the rising demand for on-board electrical power. Reinforcing this, of course, is the parallel development in the car and truck industries pushed by environmental legislation.

Military vehicle manufacturers and systems suppliers have invested heavily in the technology; often supported by the kind of ambitious government programmes alluded to above before they fell foul of the particular entropy that affects long term government plans. AM General, BAE Systems, General Dynamics, Hagglunds, MillenWorks, and Qinetiq have developed hybrid electric drive systems for UK, US and Swedish programmes, while Nexter is working on the ARCHYBALD technology development programme aimed at heavy vehicles, both civilian and military.

Hybrid Precedents

Hybrid powerplants are well established in warships, particularly in submarines, trains and heavy trucks used in quarrying and opencast mining. In these applications, a prime mover such as diesel engine, a gas turbine, or even both, drives a generator that provides current to power motors and charge batteries. Some systems include gearboxes for mechanical power transmission to final drives, while others eliminate them completely.

In warships, hybrid powerplants enable them to use complex and wide ranging speed profiles while still running their prime movers in an efficient speed range – electric motors for silent creeping, diesel engines for cruising, gas turbines for sprinting etc. A conventionally powered submarine cannot run its prime mover when submerged (unless snorkelling) and so relies on batteries or some other air independent propulsion system underwater. Giant earth moving vehicles rely on the tremendous torque from zero rpm provided by electric motors to get them moving, as mechanical gearboxes that can do the job would be enormous, complicated and expensive. Trains face the same problem to an even greater extent, as they must haul a vehicle weighing several hundred tons from a standing start, in many cases to speeds exceeding 150 miles per hour.

A hybrid powerplant can save fuel by enabling the use of a smaller, more economical prime mover without sacrificing performance, because the system supplements the main engine with battery-powered electric motors when the driver floors the throttle. The electric drive also enables the prime mover to be shut off for low speed running when it would be relatively inefficient. Modern hybrid vehicles can also recover kinetic energy, via regenerative braking systems for example, and use it to recharge their batteries. Other efficiencies are gained by running the prime mover in its most efficient speed range for more of the time, using any excess power to recharge batteries and/or run on-board electrical loads.

Modern military vehicles require more electrical power than ever before to run communication systems, command and control equip-

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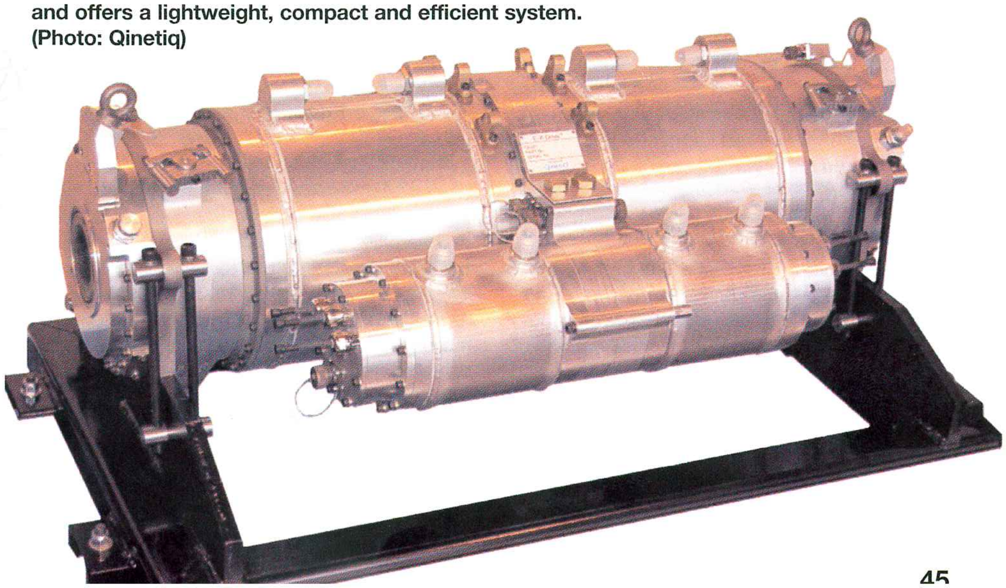
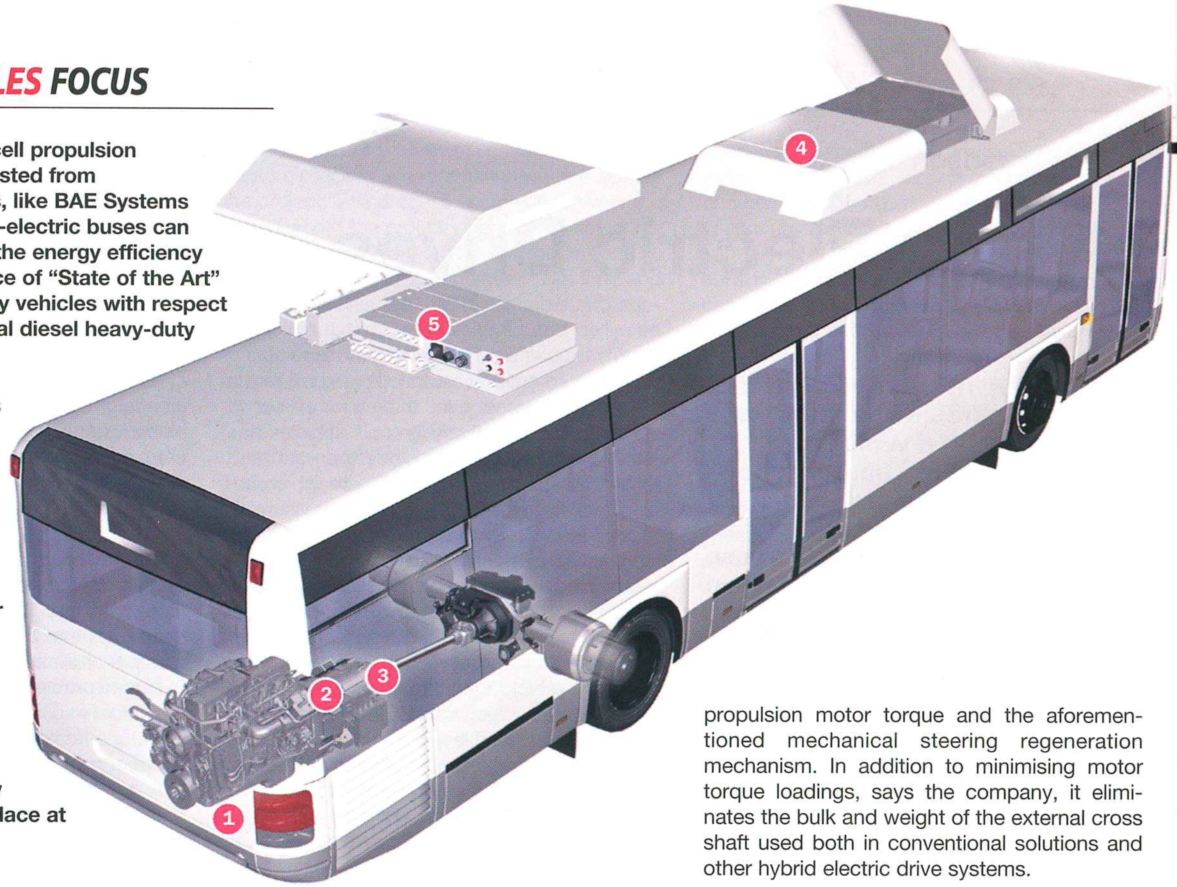
The E-X-DRIVE is QinetiQ's electric drive transmission for tracked vehicles, and offers a lightweight, compact and efficient system. (Photo: Qinetiq)





Hybrid-electric and fuel cell propulsion innovations can be harvested from commercial technologies, like BAE Systems are doing here, as hybrid-electric buses can be used to demonstrate the energy efficiency and emission performance of "State of the Art" hybrid-electric heavy-duty vehicles with respect to late model conventional diesel heavy-duty vehicles.

1 The engine;

2 The generator supplies power to the electric traction motor and the energy storage system;

3 The motor turns the drive wheels;

4 The energy storage system provides power during acceleration, including lithium-ion batteries in the HybriDrive propulsion system;

5 The propulsion control system directs the flow of energy to the right place at the right time.

(Graphic: BAE Systems)

ment, ISTAR sensors such as electro-optics and radars, remote weapons stations and IED jammers. Future systems such as electric armour will increase demands further. The ability to use all the vehicle's installed power to drive electrical systems, in theory at least, is more efficient than having one system for propulsion and another for mission equipment.

With the increased emphasis on ISTAR capabilities in counter insurgency missions, the requirement for silent watch capability is finding its way into more armoured vehicle programmes. This further increases the premium on installed electrical power and makes fuel cells more attractive, more of which later.

Hybrid electric drive systems fall into two broad categories known as parallel and serial. In the former, the internal combustion engine and the electric motor or motors turn the wheels or tracks through a gearbox, either separately or together. In a serial hybrid system, the prime mover drives the generator only. While a serial system is simpler, all the propulsion power has to go through the electric motors so they have to be larger than they would be in a parallel system with the same vehicle performance requirements. Systems of both kinds have been developed.

Survivability Benefits

Hybrids also offer survivability benefits through more flexible packaging and the elimination of driveline components that could become lethal secondary projectiles in mine or IED explosions. This is a feature from which wheeled armoured vehicles benefit in particular. By integrating the electric drive motors into the wheel hubs, all the propeller shafts, differentials, drive shafts and reduction gears associated with a conventional mechanical driveline are eliminated – so they cannot become secondary projectiles – and replaced with power cables. Elimination of all this machinery also allows the crew compartment to be carried higher off the ground for a given overall height of vehicle, making the occupants much less vulnerable to under-hull explosions. This type of design was implemented in both the General Dynamics UK AHED 8x8 demonstrator and the wheeled variant of the BAE Systems/Hagglunds SEP vehicle, a tracked version of which was also built.

Electric drive using motors integral with individual wheels enables the system to control the power sent to each wheel very precisely and this, according to GD UK, almost eliminates the off road mobility advantages that tracks offer over wheels.

The US GCV will run on tracks, and in the BAE Systems/Northrop Grumman offering, Qinetiq's E-X-DRIVE electric transmission is said to be lighter, more compact and more efficient when compared with conventional transmission systems. It also offers improved acceleration along with fault tolerance, says the company, and is configurable for a wide range of vehicles and technology insertion programmes.

Although the system includes four permanent magnet motors, power transmission within the E-X-DRIVE is not entirely electrical, both regeneration of steering power and range-shift being mechanical, the latter using a jaw clutch. This design, says the company, provides a low risk solution by minimising stress levels in the motors, gears, shafts and bearings. Using a cross shaft arrangement for mechanical power regeneration in the steering mechanism is an alternative to the use of independent sprocket drives in a pure electric transmission

One innovation at the heart of the E-X-DRIVE is the central gearbox (aka the control differential) that combines steer motor torque, propulsion motor torque and the aforementioned mechanical steering regeneration mechanism. In addition to minimising motor torque loadings, says the company, it eliminates the bulk and weight of the external cross shaft used both in conventional solutions and other hybrid electric drive systems.

Electrical Advances

Permanent magnet electric motors represent a range of technologies that have significantly improved the efficiency and power density of electric drive systems in all applications in recent years. PM motors rely on naturally occurring powerful rare Earth magnets instead of current-carrying windings (electromagnets) to create magnetic fields in stator components. This makes motors more efficient, in part because only the rotor needs to be fed with electric current.

Advanced power electronics is also a key enabling technology for hybrid electric vehicles of all kinds. Electronic motor controllers based on Insulated Gate Bipolar Transistors (IGBTs), for example, regulate the flow of power from the battery, generator or fuel cell to determine the speed and torque output of electric motors. These are much more efficient than earlier electromechanical control systems and represent an important advance in variable speed electric drives, a technology that is much less mature than the fixed speed electric drives widely used throughout industry.

New Jersey based TDI Power is an example of a company that has invested in liquid cooled power electronics for electric and hybrid vehicles for both civil and military applications. The company makes standard modular DC to DC converters and DC to AC inverters that, says the company, exceed applicable SAE and MIL standards.

Electric drives in military vehicles will also benefit from wider R&D into variable speed electric drives for industry, spurred by the promise of overall energy savings of between 15-30% that could be realised if fixed speed machines were to be replaced with variable speed drives for a high proportion of industrial loads, according to a recent study by the University of Newcastle upon Tyne commissioned by the UK Office of Science and