TECHTALK

FOCUS ON | SERIES HYBRID ELECTRIC BUS

BAE Systems can trace its hybrid bus driveline back to the 1990s in the USA, when it was used in city buses in New York City, and later Washington, D.C. and San Francisco, California. In the UK, the series hybrid driveline for the ADL E400H is celebrating its tenth birthday with a new (third) generation, launched last month.

Like the simple circuit of the same name, series hybrids constrain energy flow along a single path. As applied to the bus, it's an all-electrical one: the bus engine acts as a miniature electricity station, and has no mechanical connection to the wheels, unlike so-called parallel hybrids. In both Series-E and Series-ER Hybrid Systems, the key drivetrain components, in order of conventional drive, are: engine, generator, controller, traction motor and prop shaft. The engine is a four-cylinder, 4.5-litre Cummins ISBe4.5 Euro VI diesel; its flywheel is replaced by the integrated starter generator's rotor, and is maintenance-free.

CHANGED COMPONENTS

At the other end of the drivetrain, the traction motor has changed significantly. The previous unit, the HDS100, was an induction machine coupled to integral single-stage speed-reducing gearbox, weighing close to 300kg. The new model, DDTM100, is a direct drive, permanent magnet unit capable of up to 260bhp. This simpler design increases reliability and saves 100kg of weight.

The architecture described above omitted an all-important connection between the controller and the battery. The previous generation hybrid system used a 12 kWh lithium-ion battery pack. While this provided good hybrid performance, the cycle life of the iron-phosphate cells meant that for some operators, battery modules needed to be replaced during the life of the vehicle.

That issue has prompted two completely different, but interchangeable, types of energy storage for the new generation.

Series-ER incorporates a much larger lithium-ion battery, 32kWh capacity, based on nickel manganese cobalt (NMC) chemistry. This model promises a longer operational life than its predecessor, as well as power to perform up to 10km on electric-only mode. This capability makes the model function as a big step in the direction of electric driving, without requiring any of the refuelling infrastructure that would otherwise be required. With geofencing, it could drive up to a zone of emissions restriction on hybrid diesel power, and be switched automatically to all-electric drive at the border, and then back again to diesel-assisted power as it came out of the zone. As a rule of thumb, the bus must travel at least as far on diesel-assist as it did electric-only to recharge the batteries for another zero-emissions run, so this capability is route-dependent.

The other model, Series-E, offers much less electric-only range, and in fact a massively reduced storage capacity compared to the new battery (less than 1kWh) but, crucially, designed to last the life of the vehicle. Its battery is in fact no battery at all, but a tub of electrolytic double-layer capacitor modules, designed to cycle many more times than rechargeable batteries can. That disparity between the capabilities of the two energy storage technologies can be expressed in C-rate, the ratio of the amount of power cycled through the energy storage system (kW) to its storage capacity (kWh). According to this system, 1C is the rate that would drain the battery in one hour, 2C would drain it in half an hour. Capacitors can operate at very high C-rates (perhaps 200 in this case), whereas such levels would shorten the life of Li-ion batteries, which are happier working at C-rates below 10.

Both energy storage systems fit in the same tub, located directly above the engine compartment beneath the upper deck seats. Building in learning from previous generations, both models' cells are now fully sealed to protect against contamination from airborne particles and moisture.

Whatever storage system is chosen, the system will

drive just like a normal bus with no input from the driver. The BAE Systems software works in the background to ensure that the bus is performing its role in the most efficient way possible. With the Series-E system, the bus still feels like a hybrid with the engine shutting down around stops, a function dubbed 'Arrive-and-Go'.

SECRET SAUCE

Power and propulsion systems business development manager Matthew Lawrence calls the management of the engine, storage and traction motor BAE Systems' "secret sauce". He explains: "The control of the engine, the power needed from the generator and battery, is measured and adjusted hundreds of times every second; we control it very tightly. We're always trying to run the engine at its most efficient point for emissions and fuel, and we're trying to use the energy storage system where it makes sense to do so. It is quite a careful balance that our software has to do on a real-time basis."

That bespoke software runs in a system control unit located in the propulsion control system (PCS). Inside the PCS are hardware cards, driven by BAE Systems-designed firmware. The controller also handles power conversions, transforming the three-phase AC produced by the generator to 600V DC used by the battery. A BAE Systems-made auxiliary power system also steps that electricity down to the 28V required for on-board systems (such as lighting). These vehicles therefore do not need an alternator.

Control software parameters are all optimised to provide the performance levels for features such as hill holds and accelerations that are required by each OEM. The partnership with ADL is not exclusive; in Europe BAE Systems works with Solaris Bus & Coach and IVECO.

Electric drivetrains of course do not just take energy out of the energy storage system; they put it back in too, with regenerative braking. In this case, the electric motor performs as a retarder and the generated electricity flows back to recharge the energy storage system.

However, this important operation mode cannot be allowed to interfere with electronic braking systems from suppliers such as Knorr-Bremse and Wabco that automatically apply vehicle brakes in emergencies. Lawrence states: "There's fairly tight integration [between the two] because their system has to know how much braking torque we're providing, and how much braking torque they're providing to the wheels." The goal, he adds, is to use as much regen as it can, and try to avoid using the foundation brakes unless the bus is stationary, or unless it really needs it.

However, its energy storage is finite, and so the system protects it in the relatively rare situation of a long hill descent when the energy storage system might reach full capacity before the bus reaches the bottom, by using the generator to back-drive the engine.

Since the powertrain is decoupled from the engine, bus designers are given the flexibility to consider important aspects such as servicing and maintenance in determining where and in what orientation the diesel engine is mounted. Being mounted to the engine, the traction generator also resides in the engine bay, as does the traction motor. The propulsion control system and the auxiliary power system are mounted in a cabinet just above the engine bay, while the energy storage system is fitted below the rear seats of the upper passenger saloon. Access is via a rear-facing hatch in the E400H body.

That makes what goes under the bonnet in a series hybrid – with its mechanical, electromechanical, hardware, firmware and software systems – one of the most technologically advanced bus drivetrains going. Fortunately BAE Systems covers it all. "Our forte is the optimisation of the whole system," he concludes. TE