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Fuel cell drives for road vehicles

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Abstract

For fuel-cell driven vehicles, including buses, the fuel cell may be the main, determining factor in the system but must be integrated into the complete design process. A Low-Floor Bus design is used to illustrate this point. The influence of advances in drive-train electronics is illustrated as are novel designs for motors and mechanical transmission of power to the wheels allowing the use of novel hub assemblies. A hybrid electric power system is being deployed in which Fuel Cells produce the energy needs but are coupled with batteries especially for acceleration phases and for recuperative braking.

Keywords: Fuel cell; Road vehicle; Bus

1. Introduction

ALSTOM's main areas of business include power generation, transmission and distribution and transport, both rail and marine. Involvement in road vehicles has arisen largely through the transport business, which includes trains such as the TGV, mass transit systems such as metros and trams and trolley buses.

2. Fuel cells in buses

For any fuel-cell driven vehicle, say a bus, the fuel cell is clearly important and it is probably the main, determining factor in the system. However, it must be integrated into the vehicle, which must itself be integrated into the transport system. So, for example, the power that the fuel cell generates must be made available without unacceptable losses in the system. Fuel processing is clearly important here and has a major influence on efficiency and emissions. The fuel cell itself is sufficiently different from other power sources to require a rethink of operational strategy. Inevitably the previous experience of constructors and operators makes itself felt, but the idea here is to use this positively. It is necessary to build on positive experience, for example by using existing components as a springboard, and to avoid negatives such as design blind alleys or being insufficiently radical in approach.

3. The low-floor bus

By way of illustration, ALSTOM is involved in the development of a new generation of buses driven by fuel cells (Fig. 1). Other companies involved include Robert Wright and Sons who are leading the project.

The target performance is summarised in the Table 1. It looks, and is, ambitious. Why? The reason is that no-one, by which is meant no user, will make special allowance for the fact that a bus is driven by a fuel cell. The bus needs to have everything that is expected from a modern bus. One might say ''the bus has got to do what a bus has got to do''.

In addition to performance specifications, there are also operational requirements of the new bus. These are summarised in Table 2. Efficiency, reliability and life clearly would require a major effort of development in the fuel cell area but these factors will not be an easy ride for the rest of the system either. A diesel engine is typically designed for 1-million-km life and major operating companies only change their buses after some 15 years. Ease of maintenance is facilitated by design and, in this case, the design is highly modular, which also speeds the necessary maintenance work, increases the availability and helps

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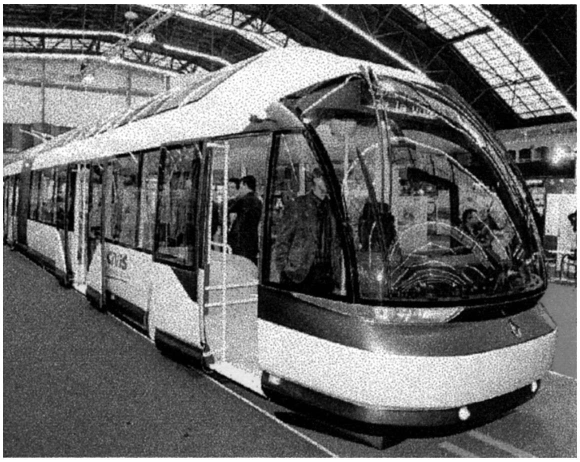

Fig. 1. A low floor fuel cell bus.

bring down costs generally. It is also possible to build on experience with related vehicles.

Table 3 indicates the project goals and expected timetable for development, prototypes.

Fuel cells are usually promoted for their environmental friendliness, low emissions, low noise, etc., and so their use is prompted by social concern. Similarly, it is necessary to ensure that transport is accessible to all, not just the able-bodied but also the aged and the disabled. This bus will incorporate a low floor design which facilitates accessibility; more about how that is achieved will be described later.

4. The drive train

The main features of the drive train of this vehicle are summarised as:

- Source of Fuel Cell not predetermined
- Probably methanol powered
- Fuel Cell/battery hybrid
- Power conditioning by modified ONIX (q.v.)
- Power Electronics and Mechanical Design enable low floor access

It may be surprising that the source of the fuel cell is not predetermined. However, ALSTOM is not presently a fuel cell manufacturer, and is concentrating development on the other parts of the system. Methanol is possibly the most likely energy source or fuel for the bus. Liquid fuel will give simpler logistics and higher storage density than a compressed gas, even though methanol stores energy at about half the volumetric density of hydrocarbon fuels. The choice of fuel affects the technologies and the developments that will be required; it also influences the operating characteristics and operating strategy for the bus.

The reasons for using a hybrid system are:

- Fuel Cell output required is smaller
- simpler control strategy
- start-up of Fuel Cell can be simpler
- limp-home capability
- facilitates recuperative braking

Fuel cells are proficient at producing energy but not necessarily at producing power. So, in this hybrid system, the fuel cell produces the energy and the battery produces the power. A smaller fuel cell is therefore required. Under acceleration, the battery comes into its own, which illustrates the second point about control strategy.

With a battery present, start-up of the fuel cell can be simpler and, should all else fail, there is the capability to limp home. Finally, the presence of a battery facilitates recuperative braking, which then improves overall system efficiency.

5. Power conditioning

Fig. 2 shows a schematic of the traction power drive train from a vehicle which can be built either as a diesel–electric bus or as a trolley bus.

Power enters either by the pantograph (top centre) or is generated by the diesel engine with its alternator (centre). In the case of the fuel cell bus, the fuel cell and battery could replace the diesel engine and alternator or the input from the pantograph. Whatever the source, the power is

Table 1
Low floor, fuel cell driven bus — Performance Targets

Target Performance
12 m, 19 Te and 18 m, 32 Te (articulated)
0–40 km/h in 15 s
80 km/h top speed
13% gradient at 25 km/h
19% gradient start

Table 2
Low floor bus, operational requirements

High efficiency
High reliability
15 years life
Easy maintenance
Competitive cost
Socially desirable features (low emissions, accessible, low noise)

Table 3
Project goals and timetable

Project commences	June 1999
Prototypes testing commences	January 2000
Fourth prototype variant testing commences	June 2000
Prototypes testing completed	October 2000
Delivery of first hybrid bus (exact variant determined from testing results and customer specification — may not include fuel cell, initially)	January 2001

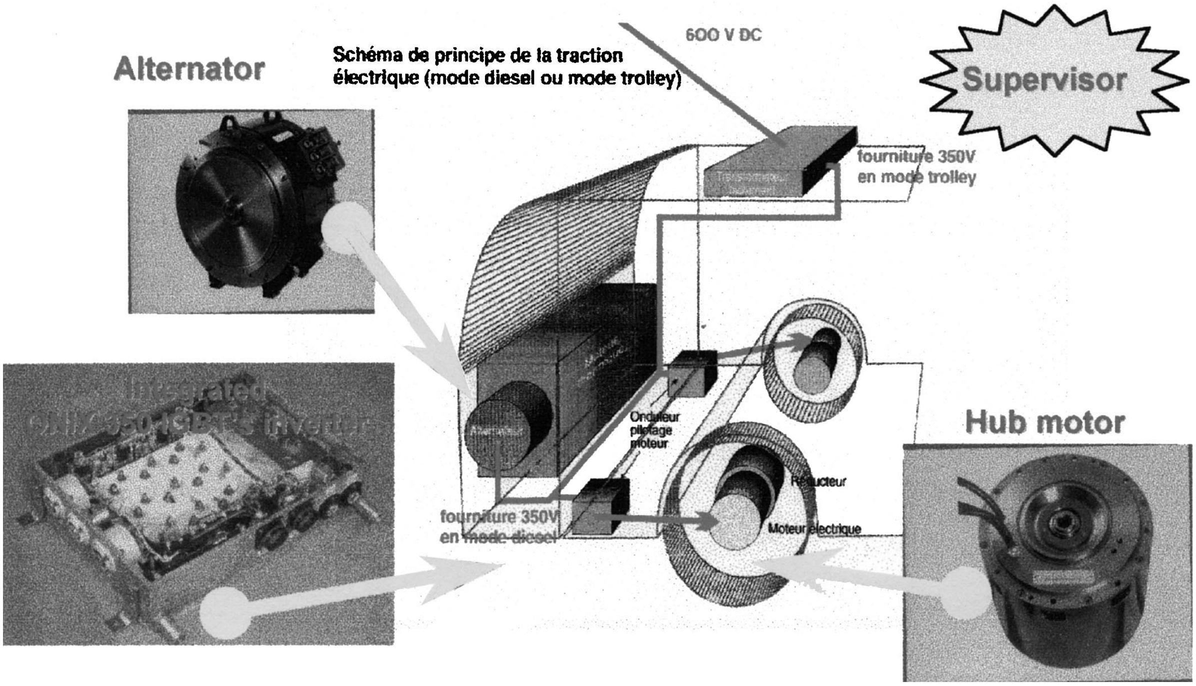

Fig. 2. Schematic view of components of a power train.

conditioned before being transmitted to the motor or motors. The way in which the power is conditioned and where it is passed is determined by a supervisory controller which interprets the commands of the driver, mediated by sensors which inform it about driving conditions. The motors are torque controlled and this allows a relatively simple control system; no differential gearbox is necessary because each driven wheel has its own motor.

The power conditioner used in this drive train is known as an ONIX 350 and each typically operates at 60 kW continuous, which it feeds to a hub motor. A point to note about this power conditioner is its small size (300 × 250 × 100 mm), about the size of a thick laptop PC. This is achieved by the use of Insulated Gate Bipolar Transistors (IGBT) and a very high level of integration in the electronics.

Fig. 3 further illustrates some recent developments in the power electronics.

The two boxes to the left, each about the size of a mini-tower PC, constituted together one leg of the three needed for a 1 MW drive using Gate Turn-Off Thyristors (GTO). Over the last two or three years this has been developed, using IGBTs, and each pair has now been replaced by the one smaller box to the right. The key is the use of modern devices and a high level of power hybrid integration; all these developments in the power conditioning and control modules require parallel development of hardware and software.

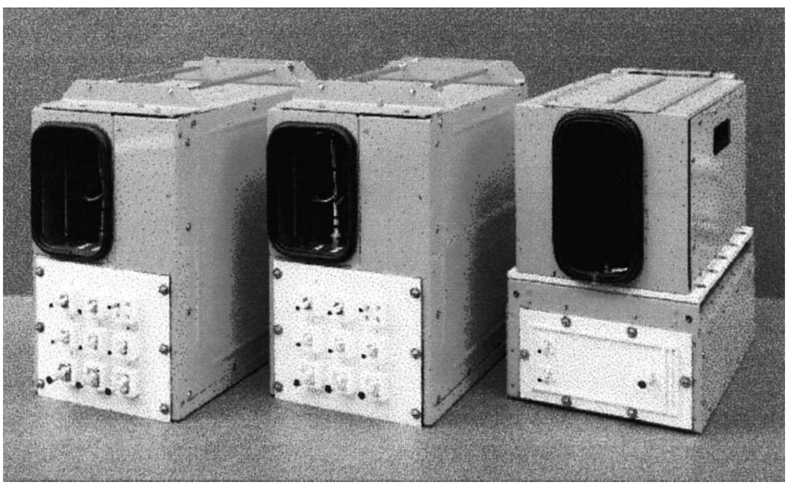

Fig. 3. 1 MW drives — one IGBT module replaces two ONIX 3000 GTO modules.

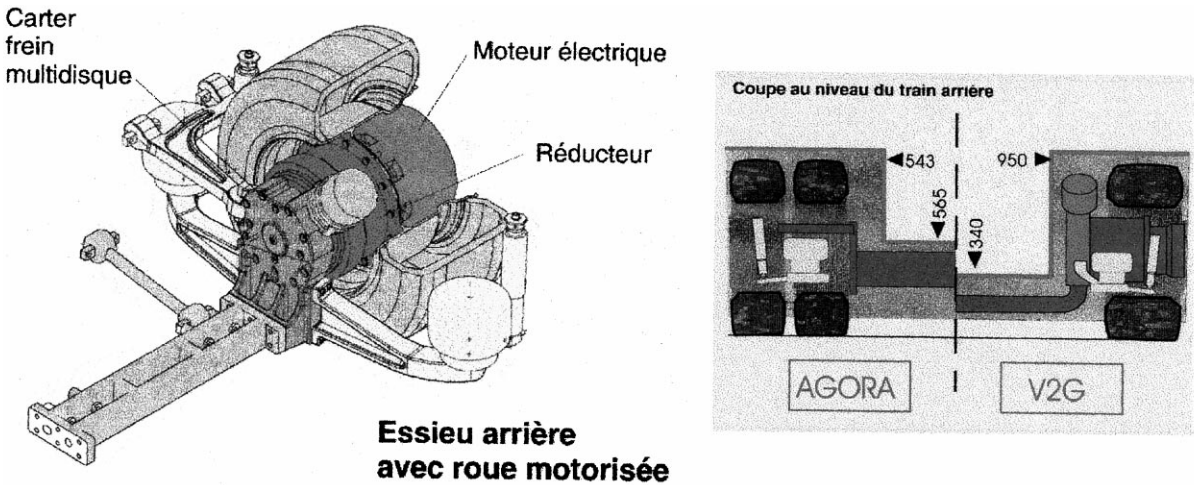

Fig. 4. Hub motors and compact driven axles (left) have enabled the low floor design (right).

The same controllers are not used for buses as would be used for trains, since they have been developed into a more suitable form. The new generation of products are significantly lower in price than the previous generation.

Fig. 4 illustrates the interaction of electrical engineering and mechanical design that has enabled the development of the low-floor design of bus. The compact design of rear drive hub is achieved by replacing the normal twin small wheels and tyres by a single large wheel and by designing an assembly that is housed within it that consists of novel hub motors, a multiple disc brake and the gearbox. The hub motors were designed expressly by ALSTOM to meet this requirement while the overall system was designed and constructed in collaboration with Renault/Iveco and will be made available to the present project with Robert Wright and Sons; an illustration of the internationality of this work. The right side of the figure illustrates how the low floor design is made possible by the new motorised hub. Fig. 5 then shows what the rear axle actually looks like.

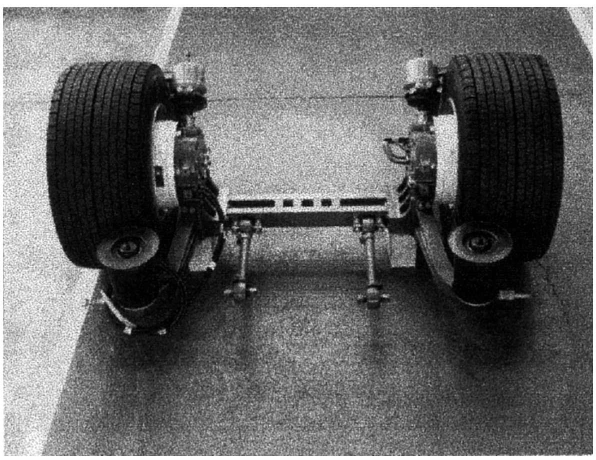

Fig. 5. Low floor bus, rear axle.

6. Summary

The fuel cell may well be the determining factor in the architecture of the system but there is much else to take into consideration. Fuel processing has barely been touched upon but clearly has a major influence on efficiency and emissions.

Electronics, power electronics and software and the interactions between them have made considerable strides and will continue to do so. The technologies such as electrical and mechanical design and overall systems design and their interaction also exert a major influence and are still progressing.

The purpose of discussing the technologies and influences, other than fuel cells, is not in any way to diminish the role and influence that fuel cell developments have made and will continue to make. However, all of the technologies must be integrated. As mentioned earlier, new technology or no new technology, it always has to be remembered that the vehicle needs to be fully capable of meeting the needs of the operators and they will not be inclined to make special allowances because it uses a fuel cell.