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Introduction of the Fuel Cell Hybrid London Taxi

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Abstract

Fuel cell electric vehicles will be an important part of the coming cleaner transportation landscape, not only helping to reduce carbon emissions but also improving air quality in our major population centres. At present, working or commercial vehicles such as taxis can contribute a major proportion of the air pollution created in and around our major population centres adding considerably not just to quality of life issues but also producing a very real impact on the health of inhabitants. This paper discusses the development, road testing and planned roll-out of fuel cell London Black Cabs by Intelligent Energy and its partners. The zero emission taxis feature a 30kW PEM hydrogen fuel cell system and a Lithium Polymer battery pack hybridised to produce a fuel cell electric vehicle with a 250 mile range and a refuelling time of only a few minutes capable of meeting the demanding duty cycle of one of the icons of London and British transport.

Keywords: list 3-5 fuel cell, PEM fuel cell (proton exchange membrane), HEV (hybrid electric vehicle), hydrogen

1 Introduction

The impetus to reduce carbon emissions of road vehicles had led to significant advancements in alternatives to conventional internal combustion engined (ICE) vehicles. In addition to climate change concerns, the effect of transportation emissions on human health is a major area of concern. The air quality in major cities can be extremely poor, due to high levels of particulate matter (PM10) and nitrogen dioxide, and it has been estimated (see for example [1]) that air pollution contributes to 3,000 premature deaths every year in London.

To that end, the London Mayor has pledged via a draft air quality strategy to work with the taxi manufacturing industry to develop an affordable zero emission taxi such that all new taxi's entering service from 2020 be zero emission [2].

The development of hybrid propulsion systems which utilise a combination of ICE and battery power can lead to significant improvements in vehicle emissions. However, they do not offer zero tailpipe emissions which are desirable for congested inner city areas. Fuel cells are often considered as offering the best long term prospect as an alternative to the ICE, especially during urban use as their peak efficiency is more closely matched to the road load requirements, thus reducing fuel consumption. Of the various types currently under development, proton exchange membrane (PEM) technology is generally regarded as the most suitable for road vehicle applications. When used in a hybrid arrangement in conjunction with a battery, the benefits of both technologies can be exploited.

According to Transport For London statistics [3] there are over 21,000 licensed taxis in London, thus elimination of tail pipe emissions from a proportion of these vehicles could have a significant impact on overall vehicle pollution levels in the city. A study of driver's preferences for fuel cell taxis [4] has indicated that financial benefit principally influences the acceptance of drivers in the short term whereas environmental benefits are more important longer term. In addition, drivers also commented that they were most satisfied with the reliability, top speed and acceleration of the conventional vehicle. Interestingly, as taxis are closely regulated by the Public Carriage Office (PCO), drivers generally reported that there would be no rise in concern with regards to the safety when using an approved fuel cell vehicle when compared to a conventional diesel equivalent. A full Life Cycle Analysis of possible alternative vehicle technologies for the traditional London Taxi has been performed [5] regarding its energy consumption and CO_2. A plug-in hybrid electric fuel cell vehicle, a hybrid electric fuel cell vehicle and a battery electric vehicle (EV) were considered as alternatives to the traditional ICE diesel London Taxi. The plug in hybrid electric fuel cell (PHEV-FC) Taxi resulted in the lowest life cycle analysis (LCA) energy consumption and CO_2 emissions values with a reduction of 55% and 69% respectively when compared to the original ICE diesel Taxi.

This paper discusses the development of a fuel cell stack and system for integration into a conventional London Black Cab. Testing and planned rollout of a small fleet of vehicles into London is also discussed.

2 Taxi Requirements

In order for a fuel cell based taxi to be authorised for use in London it must be designed to meet the stringent requirements of the conditions of fitness regulated by the Taxis and Private Hire department of Transport for London (TFL). In addition, its performance and cost should be comparable to that of the conventional approved London Hackney carriage. With that in mind, a TX4 from The London Taxi Company was considered as the base vehicle with as many off the shelf components as possible used. The basic performance targets for the vehicle are provided in Table 1:

Table 1: Vehicle performance targets

Acceleration	Better than TX4
Top Speed	75 mph
Range (not including battery)	250 km (full days usage)
Refuelling Time	< 10 minutes
Hackney carriage Regulations	Compliant
Gradability	>25%
Temperature range	-18^{o}C to +37^{o}C
CO_2 Emissions	0 g/km

To achieve the vehicle requirements, a fuel cell range extender hybrid powertrain architecture was developed as an alternative to the conventional ICE propulsion system of the TX4 taxi (Figure 1).

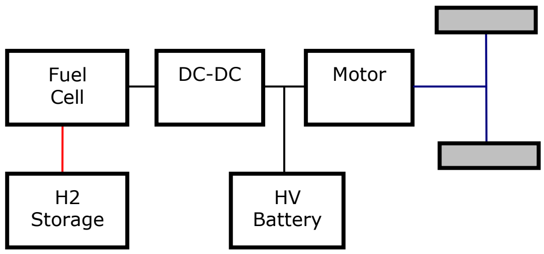

Figure 1: Powertrain configuration

Given that the internal combustion engine has been removed, the use of an electro-hydraulic power steering pump was used along with a slip control boost system (SCB) to allow the use of regenerative braking whilst maintaining the regulatory requirement for fitment of an anti-lock braking system (ABS).

The high level control regime implemented is such that the vehicle operates on battery power only if the fuel cell power requirement is less than its peak efficiency point. This takes account of the battery state of charge, hence even at low vehicle speeds the fuel cell may operate in order to charge the battery. For power demands above the peak efficiency point of the fuel cell, the vehicle is effectively driven directly from the fuel cell with the battery assisting during transients. Hence, the powertrain configuration is a series hybrid configured as a range extender by operating the fuel cell system at its peak efficiency point where necessary. To further improve efficiency, energy is captured to charge the battery during braking.

3 Fuel Cell Hybrid Powertrain

The fuel cell stacks developed by Intelligent Energy are based on a proprietary technology whereby heat that is generated during the electrochemical process is removed via evaporation of injected water. This eliminates the need for a separate stack cooling loop as used on similar technology and results in both a simplified system balance of plant and reduced fuel cell stack size as specific cooling channels are not required (Figure 2). This is fundamental to the design philosophy of the fuel cell stacks which were developed from the outset with mass manufacture in mind. In addition, on the grounds of improved volume density and robustness, metallic bipolar plates are utilised as opposed to a graphite based alternative. These features are particularly beneficial when considering motive applications.

The core fuel cell stack building blocks utilised are based on 192 individual cells connected in series.

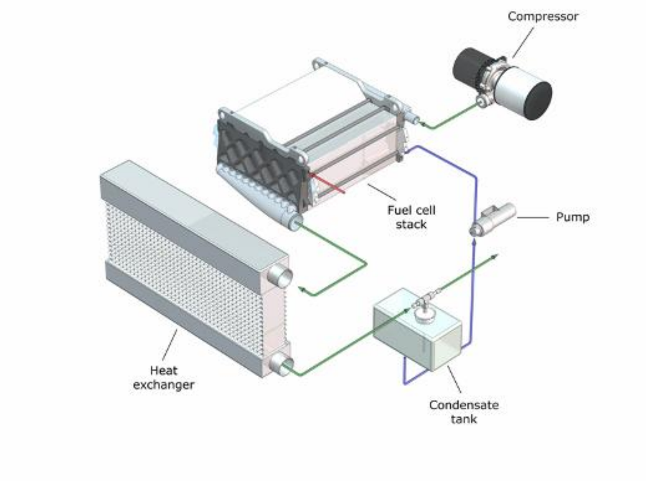

Figure 2: Intelligent Energy fuel cell system architecture

The stack has a length of 290mm, height of 194mm, depth of 154mm and a mass of 32kg. A single 192 cell evaporatively cooled stack is capable of achieving in excess of 18kWe over a 0-150A range, as shown in Figure 3.

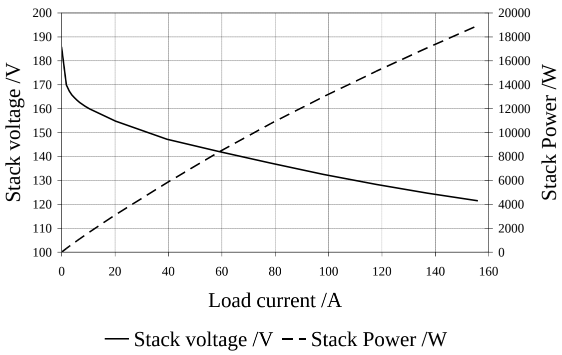

Figure 3: 192 cell fuel cell stack polarisation curve

Two 192 cell fuel cell stacks connected in series are utilised in conjunction with the required balance of plant to provide a fuel cell system capable of 30kW net electrical output. In addition to the main fuel cell stack module a number of other subsystems are required for operation. An air delivery module comprising a filter, compressor and flow meter arrangement is used to provide air to the cathode of the fuel cell stack. An anode subsystem manages the hydrogen delivery and purge and a fuel cell coolant module manages the water injected into the fuel cell stack. A heat exchanger module manages the removal of heat generated by the fuel cell system and high and low voltage electrical subsystems are employed. Automatic operation is via an electronic control unit (ECU) which also communicates to the supervising vehicle ECU via controller area network (CAN).

In addition to the 30kW fuel cell system, the powertrain comprises a 14kWhr lithium polymer high voltage battery pack, a DC/DC converter to regulate the fuel cell system and a motor with peak and continuous power ratings of 100kW and 55kW respectively. Hydrogen is stored onboard the vehicle in gaseous form at 35MPa, although an optional 70MPa tank can be fitted within the same packaging. The 35MPa solution was chosen as this fits with the current and imminent UK and London hydrogen infrastructure. At 35MPa, 3.7kg of hydrogen is stored on board.

The motor can be driven via a combination of either or both of the battery and fuel cell system, with the optimum blend selected by the powertrain control system. When the vehicle is stationary and the battery requires charging, the fuel cell is operated at its most efficient operating point (58% net system efficiency based on the lower heating value of hydrogen) – external battery charging is not required in standard format in order to remove the need for external charging. However, the vehicle does have plug-in hardware capability hence the vehicle control system could be configured to enable this functionality.

4 Vehicle Integration

The fuel cell system comprises a number of subsystems; fuel cell stack power module, high voltage module, low voltage module (including the main ECU), thermal module, coolant storage module, exhaust module and air blower module. The core of the fuel cell system is the stack power module which is installed within the transmission tunnel void. The air blower module is installed in the 'engine compartment' of the vehicle with the remaining modules mounted from beneath the vehicle on either side of the stack power module.

In order to satisfy taxi turning circle regulations defined by Taxis and Private Hire, rear wheel drive is maintained. The motor is mounted inboard at the rear of the vehicle with a fixed ratio gearbox and differential providing the connection to the driven wheels. The motor controller and main high voltage DC/DC converter are housed at the rear of the trunk along with the charger for the high voltage battery pack for plug-in capability as noted above. The high voltage battery pack comprises seven modules which are installed as a five module pack plus two further satellite units underneath the passenger area of the vehicle.

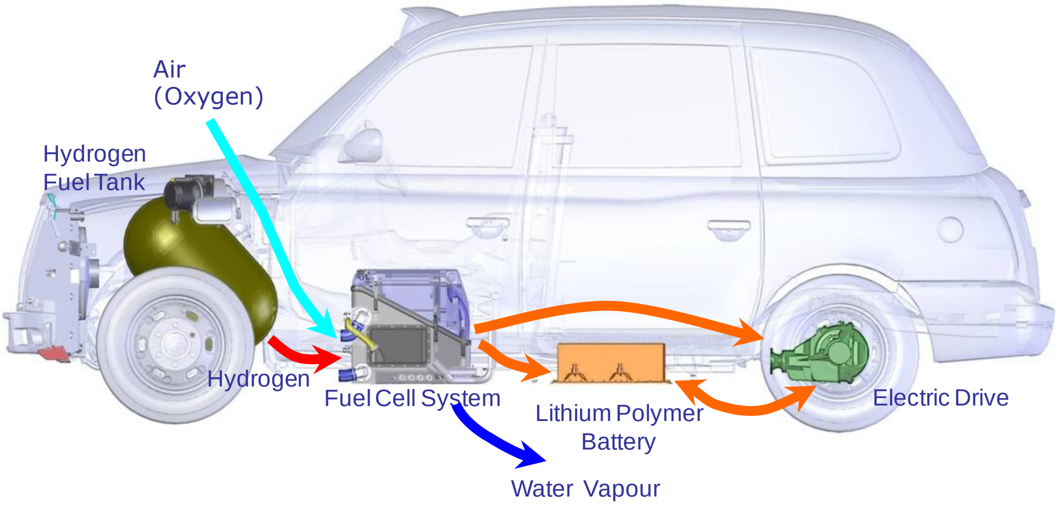

Figure 4: Powertrain Integration

The split configuration allows installation of the battery pack with no major modifications to the conventional vehicle chassis. Various locations for the compressed hydrogen storage tank were proposed with the chosen solution located in the engine compartment of the vehicle. This allows use of a single tank off-the-shelf solution thus minimising the chance of leaks due to manifold interconnections of multiple cylinders. The tank is supported in a cradle which is installed at 45^{o} within the 'engine' bay. In the event of an impact the tank and cradle are designed to submarine underneath the driver. An over-pressure relief is fitted to the storage tank such that if the pressure increases above an upper threshold the hydrogen is released in a controlled manner to an exit behind the 'for hire' sign on the roof of the vehicle. Figure 4 details the vehicle installation of the main powertrain components.

5 Vehicle Testing

An initial batch of two prototype fuel cell hybrid London 'Black Cabs' were developed and manufactured with both vehicles certified for use on public roads in UK. There are very few cues externally of internally to suggest the zero emission status of the vehicle (Figure 5) – except for the decals the lack of a conventional tail pipe is the most obvious clue externally along with changes to the instrument pack internally in order to indicate hydrogen storage pressure and high voltage battery state of charge to the driver.

Figure 5: Prototype Fuel Cell Hybrid Taxi

Over 9,000 miles have been completed to date by the initial two vehicles on a combination of private test track and public roads, although it should be noted that during this development period the vehicles were not used to carry fare paying passengers. During this time the vehicles were operated on a number of duty cycles including both urban and suburban operation with some operation in London according to simulated taxi usage (Figure 6).

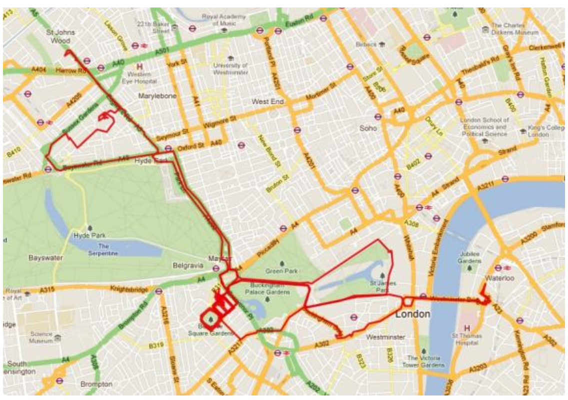

Figure 6: Taxi Development in Central London

6 Vehicle Demonstration

Following the development and testing of the two prototype fuel cell hybrid London taxis, in summer 2012 a small fleet of vehicles will be manufactured and deployed for use in London. A dedicated hydrogen fuelling station will be installed for use by the taxis and data will be gathered in order to analyse the operation of the vehicles in order to both better understand the requirements and aid the development of future vehicles.

In parallel to this activity work continues on the development of the fuel cell system with the next generation to feature improved volumetric and gravimetric power density. This is largely due to improvements in the fuel cell stack performance and manufacturing methods, although work is also underway with Tier 1 automotive suppliers to improve balance of plant components.

7 Conclusions

This paper has described the development and introduction of a zero emission fuel cell hybrid London taxi. A conventional TX4 taxi from The London Taxi Company was used as the base vehicle with the conventional diesel based powertrain replaced by a zero emission alterative. Particular requirements of the vehicle were that it be capable of achieving a full days use on a single fuel fill or recharge, and that this fuel fill or recharge process be carried out in a time comparable to that of the conventional diesel alternative. To achieve this, a PEM fuel cell and lithium Polymer range extender powertrain was developed and implemented in two prototype vehicles. Decals aside, there is very little internal or external difference apparent when comparing the fuel cell hybrid taxi with the conventional diesel variant - the lack of a tailpipe being the most obvious clue. The vehicles have been tested on a combination of both private test track and public roads, and an additional fleet of vehicles will be manufactured and deployed for use in London in Summer 2012.

Acknowledgments

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