Current status and operating principles of hydrogen power plant in urban transport

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Abstract. The article describes the current status of hydrogen power engineering and electric transport as the main force for a branch development. Modern transport industry turns to the environmentally friendly hydrogen technologies and an optimization of energy resources consumption. The development of new high-tech industries is very important in terms of requirements for environment safety and an emissions level. Gradual development of hydrogen fuel vehicles will reduce a cost of production of one vehicle and make them attractive for using in countries around the world. The rising demand for hydrogen vehicles forces the science to improve the technology of conversion of hydrogen energy into electrical. The development of new control systems for such vehicles, which have high requirements for a fuel quality and the optimization of power plant load, is also stimulated by a demand for hydrogen vehicles.

1. Introduction

The sector of hydrogen fuel cells (HFC) continues its growth. Thus, in comparison with 2017, the production costs have been reduced, FC market has involved new participants, and major FC producers such as “Plug Power”, “Ceres Power”, “Hydrogenics”, “Ballard”, “Caetano” and “FuelCellEnergy” have invested millions of dollars in the development of this industry. In 2018 the total power put into FC service accounted for 145 MW, which corresponded to 74000 devices. Approximately 11000 FC vehicles were developed in 2018.

Table 1. Dynamics of fuel cell transport development

|                | 2014 | 2015 | 2016 | 2017 | 2018 |
|----------------|------|------|------|------|------|
| Shipments (1000 units) | 2.9  | 5.2  | 7.2  | 10.6 | 11.2 |
| Megawatts       | 37.2 | 113.6| 307.2| 435.7| 562.6|

Asian markets have forced the FC development. There is a substantial demand for this technology and a qualified human resource. Figure 1 shows the number of FC (1000 units) sold during the 2014-2018 period.
In 2017 “Hyundai” announced the supply of 1000 transport units with FC for Switzerland, and tentatively started a similar program in South Korea for the period of up to 2022 with expanding production plans up to 40000 units per year.

However, the absence of infrastructure coupled with the difficulties of FC vehicles licensing slows the growth of production capacities. Many large cities consider this alternative because of existing restrictions for the diesel buses and stringent requirements for air purity. An adaptation of existing charging infrastructure for hydrogen is more profitable than installation of new electric charging stations. Besides, the speed of hydrogen refueling, and the autonomous motion distance of hydrogen buses will be higher than analogues with batteries [1, 2].

2. Fuel cell electric buses
Fuel Cell Electric Buses (FCEBs) are considered as a promising technology for environmentally safe future cities. European countries have already followed a stable policy of this transport type integration in existing motor parks of the cities. The result of this policy is the program “Joint Initiative for Hydrogen Vehicles across Europe 2” (JIVE 2) which is financed by the interstate fund “Fuel Cell and Hydrogen: Joint Undertaking” (FCH-JU). In accordance with this program it is planned to purchase 152 FCEBs and then sell them in European cities. According to the results of the JIVE 1 program, which was running a year earlier, for a period of up to 2023 a delivery of almost 300 FCEBs and several petrol stations to 22 cities in Europe is expected. Among the producers of FCEBs in Europe, such companies as “Van Hool” (Belgium), “ebe EUROPA” (Germany), “Autosan” (Poland), “Mercedes/Evobus” (Germany), “Wrightbus” (Northern Ireland), “APTS/Phileas”, “VDL” (Netherlands, Belgium) should be mentioned. Major engineering centres for implementation of the hydrogen technologies such as “Arcola Energy” (United Kingdom) have been also developing.

The main FC type which is used in the FCEBs’ composition is Proton Exchange Membrane Fuel Cell (PEMFC). Other FC types are less suitable for generating power or portable application [3]. The main characteristics of FC for a transport application are shown in table 2.

| Power range      | 1-300kW                          |
|------------------|----------------------------------|
| FC technology    | Proton Exchange Membrane Fuel Cell (PEMFC) |
|                  | Direct Methanol Fuel Cell (DMFC)  |
| Application      | Fuel Cell Electric Vehicles (FCEV)  |
|                  | trucks and buses                 |
|                  | rail vehicles                     |
|                  | autonomous vehicles               |
3. Topologies of power plants and principled approach to a fuel cell control while driving

Existing power plants with FCEV are typically performed using a parallel hybrid type and differ in the number of DC/DC converters and electrochemical storage devices (ES) (Figure 2) [4].

![Figure 2. Topologies of FCEVs.](image)

Accumulator battery (ACB), supercapacitor battery (SCB) as well as their combination (ACB+SCB) could be used as an electrochemical storage device [5–7]. The model of the power plant control system based on the Fuel Cell Systems (FCS) must include the characteristics of two energy sources in frequent starts and brake modes.

In general, this model can be performed according to the type of continuous operation of the FCS and FCS inclusions in certain required power values (Figure 3).

![Figure 3. Two typical operating principles of FCS: (a) FCS works constantly, (b) FCS works periodically.](image)

Thus, the approach (a) is characterized by the following aspects:

- FC life span is prolonged because in terms of chemical technology, repetitive on/off modes have a negative impact on the device materials [8].
- Increase in the hydrogen fuel consumption is possible.
- In continuous operation mode of FC (power does not fall below the value $P_{\text{min}}$) a load distribution with electrochemical storage should be supported so that the total energy flow provides required dynamic characteristics of the traction drive.
- The continuous FC operation can result in recharging the electrochemical storage device in a regenerative braking mode.

The full movement cycle of FCEV by type (b) can be divided into several stages:

- “no-load operation” (FC switching on, time period is $t_0$–$t_1$);
- “acceleration mode” (FC power increasing up to $P_{\text{max}}$, time period is $t_1$–$t_2$);
- “speed increasing period” (movement by means of other storage, time period is \( t_2 - t_3 \));
- “regenerative breaking” (FC is switched off, other storage receives energy, time period is \( t_3 - t_4 \)).

To identify the characteristics of the FCS and electrochemical storage device, loads occurring inside the traction drive in real urban movement must be defined. The necessary measurements were made by means of the on-board registrar for the trolley running along the route in Novosibirsk (Russia) [9]. The received statistical data help to assess the level of the average power consumption (traction drive) and speed.

The analysis of the average values within the average intervals from 60 seconds to 120 seconds was held. Figure 4 shows that the approximation function of the average power to the average speed does not depend on the selected interval.

It must be considered that the average power of 25kW is enough for movement of an 18t electrical bus with the average speed within 20 km/h [10].

4. Conclusion
This article presents an analysis of the current status of hydrogen power engineering industry, particularly in the electric transport complex. The main directions of development and improving the availability of hydrogen transport are identified.

Possible topology of power plants for hydrogen vehicles are investigated; special aspects of operating modes of fuel cell power plants were determined using different principle approaches.

It is offered to use real operational data of the existing urban vehicle to justify dynamic characteristics of hydrogen transport. An average approximating power function depending on the average speed is formed and based on data obtained from the onboard registrar.

Further study will be focused on determination of the energy storage device type and parameters, and characteristics of fuel cell systems. The development of the control system based on data presented in this article is going to be made.

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