Model-based and signal-based pem fc diagnostic approach techniques

Science, Biology

Among modern world’s main issues, potential energy shortage for the years to come and climate change consequences are some of the main ones according to several institutions around the globe. Primary energy consumption has been increasing at a rate of 2. 5% recently. According to the same studies, coal consumption has even increased in recent years with a maximum of 29. 9% of global primary energy in year 2012. At the same time, the aftermath of the earthquake and its consequent tidal wave (year 2011) in Fukushima’s nuclear power plant, Japan, encouraged the government in that country to reduce the countries dependence on nuclear energy by 89% (6. 9% around the world). Taking into consideration that efficiencies achieved by coal-fired power plants can reach 41% it has been stated that reducing heat waste rate is one of the aims for the future to come. This state of events is forcing political authorities around the world to seek for new ways of supplying energy which manage waste energy properly. For residential uses the energy consumption can be classified as 27% of electrical energy and 38% of thermal energy around the world. In this context, hydrogen as a fuel is a promising solution for future energy applications, more specifically combined heat and power (CHP), as it can be used for generating both electrical energy and heat, increasing its global efficiency up to 80% when recovering the released heat and using it properly. It is, at the same time, an energy source much more environmentally friendly than fossil fuels provided that the hydrogen itself has not been obtained by reforming conventional fuel. Certain strategies have been proposed recently to use the heat released by the high temperature fuel cell studied for heat requirements in housing facilities, including compressors to supply the air to the cathode, heat exchangers to treat the exhaust heat and electrical power converters to supply reliable electrical voltage. These methods have been widely applied in countries such as Germany, the United Kingdom and especially Japan whose governments have encouraged residential facilities based on PEMFC.

Fuel Cell Technologies

A FC is defined as “ an electrochemical converter which continuously converts the chemical energy from a fuel and an oxidant into electrical energy, heat and other reaction products”. Both fuel and oxidant are continuously supplied at the same pace they are being consumed.

Material problems

Corrosion of metal

Each cell is composed of different layers, presented as follows:

- A porous anode. Gaseous fuel diffuses through the pores of the anode to reach the interface with the electrolyte able to conduct ions, where it is oxidised; electrons are conveyed from the anode to the cathode by an external circuit.
- A porous cathod. The gaseous oxidant (oxygen) diffuses through the pores of the cathode to reach the interface with the electrolyte, and is reduced.
- An electrolyte, which conducts the ions from one electrode to the other.
- Bipolar plates, conveying the reactants to the electrodes, evacuate the reactants in excess as well as the products of the reaction (mostly

water). Heat is also released and needs to be redirected with additional equipment. All these layers are sealed using silicon to prevent hypothetical gas and cooling fluid leakages and constitute the so-called stack of layers. A PEMFC has an anode which is fed with pure hydrogen (H2) and its cathode with pure or ambient air oxygen. Hydrogen is oxidised at the anode and consequently H+ (protons) flow across the polymer membrane from anode to cathode. Simultaneously, the cathode is fed with electrons collected by the bipolar plates. At the cathode, oxygen, electrons and protons meet to produce water. The chemical redox semi-reactions are H2 -> 2 H+ + 2 e- 1/2 O2 + 2 e- + 2 H+ -> H2O. This process leads to the production of electric power, thermal power and water.

Hydrogen flow is directly proportional to the electrical current, I, and this way current and released heat can be linked. Real fuel cells present; however, cell voltage decreases when compared to the Nernst reverse voltage, VN, with or without load. The main cause of this decreasing is the cell's losses. These issues can be described as follows:

- The activation energy needed to trigger the redox reactions, especially when the current is low.
- The ohmic resistance due to ion transport through the membrane, the electrodes and the bipolar plates. The one caused by the bipolar plates can be generally neglected.

- The concentration voltage droop due to the transport of matter through the porous electrodes and more specifically through the gas diffusion layer, which is dominant at high current. To characterise PEMFC's static electric performances, the so-called polarisation curve is defined. This curve is obtained by plotting the cell voltage versus the current density.

PEMFC applications

Both LT-PEMFC and HT-PEMFC are being applied in several ways and fields. These are often classified in stationary and non-stationary applications, understanding non-stationary as those for transport systems:

- Non-stationary applications: due to its size and relatively low weight, PEMFC are a valid alternative to conventional vehicle powering methods. Vehicle powering using LT-PEMFC is especially used nowadays in buses and also in hybrid vehicles.
- Stationary applications: residential heat and power generation, trying to be an alternative to conventional generation of heat and electrical power separately through the gas and electrical public distribution grids. Other stationary applications are industrial ones like wine industry.

Finally, another option is using this kind of fuel cells for emergency systems implemented in hospitals, data centres or scientific facilities, among others. Among all applications enlisted, comfort applications for residential uses have been a key policy adopted by several governments around the world. According to some authors fuel cells offer, compared to conventional μ-CHP technologies such as higher electrical efficiencies, lower heat to power ratios, reduced noise and vibrations during operation and flexibility of fuel use. A future in which several kinds of renewable energies are used in µ-CHP has been devised by some studies. In this context, the use of fuel cell technology is a promising option which can lead to significant reductions in CO2 emissions and operating costs for the user. With regards to the type of fuel cells being used, the LT-PEMFC and the intermediate to high temperature SOFC currently show the greatest promise, with most building integrated projects focusing on these two technological variants. PEMFC offer quick start up time, power modulation and useful direct hot water output. Project objectives One of the main problems of fuel cell models is their high number of parameters and the complexity of the mathematical models that describe their behaviour. Many of these parameters are usually difficult to tune experimental tests and might change with time. In addition to this there exist many inner variables which are no measurable. Due to this it is difficult to build simple models which describes its behaviour and allow to handle Fuel Cell efficiently or estimate its lifetime and state of health. Many methods have been proposed to analyse the state and state of health of PEM Fuel Cell. Two main categories can be distinguished, model-based methods and signal-based methods.

Model based methods use a system model to estimate inner variables and from that determine most relevant characteristics and state of health. On the other hand, signal based model do not use a model explicitly, but are based on analysing the relationship between different measurable signals. The two groups involved in the project have extensive experience in the modelling, design of control systems and supervision of high and low temperature PEM fuel cell. This has been reflected in numerous international publications.

The IRI-UPC group has worked in recent years in the development of distributed parameters model of PEM batteries. Based on these models, state observers have been developed to estimate the internal variables of fuel cells. These estimations are easily usable both in control systems and in health status analysis mechanisms. The FCLAB group has extensive experience in the development of the fuel cell state of health analysis, mainly these algorithms are based on the analysis of the signals that are usually used.

These methods have generated excellent results in the characterization of the useful life of fuel cells and their health status. Although these two approaches are used to describe the same systems, many times are treated as two separated fields that do not interact between them. Additionally, the relationship between them is not well understood.