Development of a polymer electrolyte membrane fuel cell power generation system

Power generation systems based on fuel cells represents a promising technology for the future. The main reasons are related to the efficiency of the energy conversion which is higher than that of other technologies and to the lower emissions level. This report presents the theoretical and experimental activities carried out in the development phase of a power generation module based on the polymer electrolyte membrane fuel cell (PEMFC) technology.

The present work proposes a model which integrates the finite element method in a dynamic simulation, in order to achieve a higher accuracy and the possibility to investigate the influence of various parameters on the fuel cell system dynamics. The model (Figure 1) is implemented using Matlab/Simulink and consists of two interacting main subsystems that calculates the fuel cell power response and the stack thermal behavior. The first simulates the mass transport and electrochemical phenomena using a model implemented in Femlab, and considers as input parameters the bipolar plate channel geometry, reactants pressure, flow rate and composition and the stack average temperature. The last parameter is also evaluated by the second model, implemented also in Femlab, which considers the cooling channel geometry, cooling air flow rate and ambient temperature. Both models were validated using the experimental data acquired on a Ballard Nexa 1.5 kWe PEM system. The results prove that integrated model simulates with accuracy the dynamics of the PEMFC system and the interaction between the stack and the auxiliaries. The proposed model was used as a predictive tool in the development phase of the power generation system for the assessment of the cooling fan control strategy.

In order to verify the developed model and characterize the fuel cell stack operation a test bench was designed and built. Also, a dedicated data acquisition and control software was developed and successfully implemented. The test bed is equipped with the necessary instrumentation to characterize the fuel cell stack operation and to control its main functions.

The main subsystems of the test bed are: fuel and air supply, thermal management, electrical load, control and safety.

The fuel supply subsystem consists of hydrogen storage tanks (standard compressed hydrogen tanks or metal hydride tanks) and pressure regulators. A pressure transducer monitors fuel delivery pressure to ensure an adequate fuel supply.

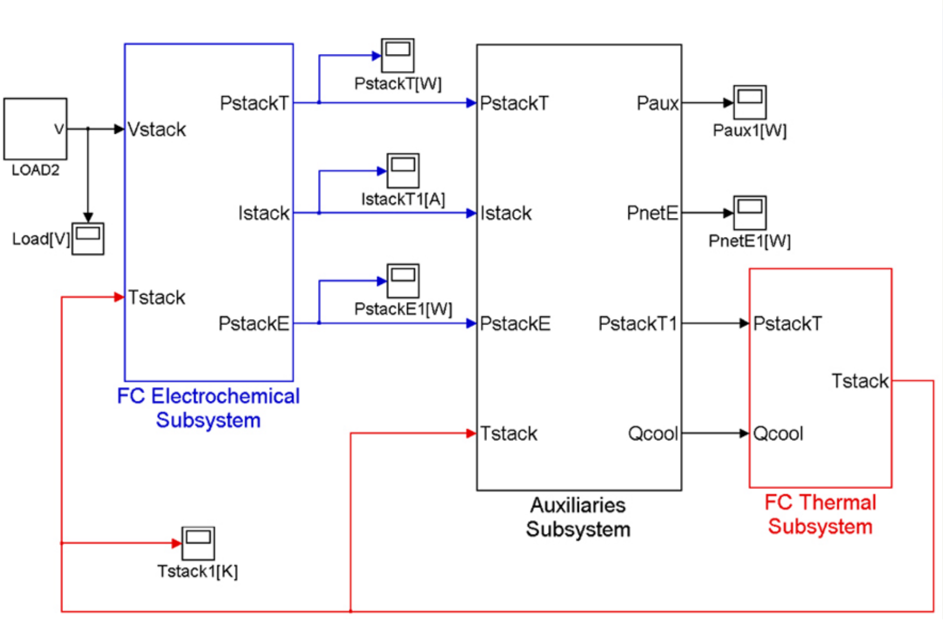

Figure 1 Simulink block diagram of the integrated model

The air supply subsystem is designed to feed the fuel cell stack with humidified air at different pressure and flow rates. The air humidification is performed using a simple bubble type humidifier, or (for larger stack system) a humidity exchanger that transfers both fuel cell product water and heat from the wet cathode outlet to the dry incoming air.

An electrical load is required in order to simulate a wide variety of practical loads. Two types of electrical loads were used: an electronically controlled system capable of operating various configurations (constant current, constant voltage, constant resistance or as a transient load) which is able to cover loads up to 300W and a resistive load which was used up to 1500W.

Regarding the thermal management, we can identify two situations: single cells and stack tests. For the single cell tests, due to the low power output, there is no necessity to dissipate the small amount of produced heat. In this case, in order to analyze the temperature influence on the fuel cell performance, a controlled heating system was used. For the stack tests, considering the configuration of the tested systems, an air cooling system was used. It consists of a group of air blowers that promote the forced convection cooling of the stack. The blowers are electronically controlled using the signals from the temperature sensors placed on the stack.

The test bed operation is automated by an electronic control system implemented using the National Instruments CompactRio hardware. The control system receives various input signals from different sensors: fuel cell stack temperature, hydrogen and air pressures, hydrogen leak concentration, fuel cell stack current and voltage and air mass flow.

Analog and digital control signals are issued from the control board to regulate system operation. Digital controls are used for opening and closing the hydrogen solenoid valve and the purge valve. Also, the speed of the air compressor can be controlled using a digital output. The speed of the cooling fans is controlled using an analog output.

The monitoring and control software was realized using National Instruments LabView 8.1 software. The controller can operate as a stand-alone unit or interfaced with an external PC.

The controller communicates with the computer using an Ethernet connection. All the acquired data are saved on a log file, which can be accessed with Excel or Matlab for further processing.

In order to provide safe operating conditions for the fuel cell stack and peripherals, the hydrogen concentration is continuously monitored with two independent devices.

The test bed, schematically presented in Figure 2, was used to analyze various configurations of single cells or stacks. The preliminary experimental tests were conducted with 5 and 25 cm^2 single cells using Electrochem or in house built bipolar plates, in order to validate the data acquisition and control software, and to understand the influence of various parameters on fuel cell operation. Also, the test bed control section was used as a secondary data acquisition and control system for the Ballard Nexa module, in order to test the software capability to work with large amount of data and control the main stack functions.

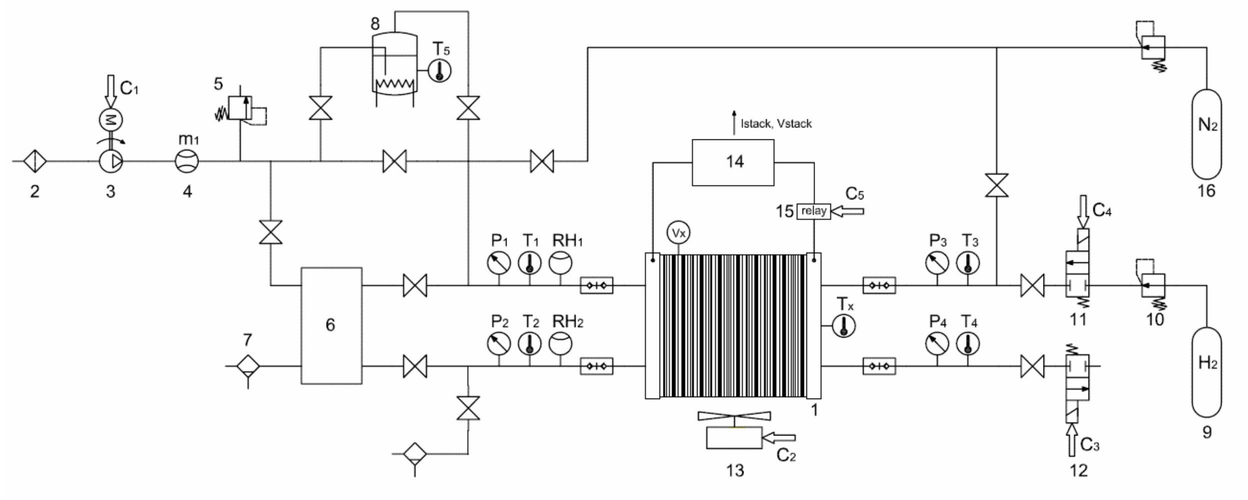

Figure 2. Test bed diagram (1. stack, 2. filter, 3. air compressor, 4.air flow sensor, 5. relief valve, 6. humidifier, 7. water trap, 8. bubbler, 9. hydrogen tank, 10. pressure regulator, 11. hydrogen inlet valve, 12. purge valve, 13. cooling fan, 14. load, 15. relay, 16. nitrogen tank.)

The previously described model and the dedicated test bed were used in the design and development phase of a new power generation system based on a 25 cells stack (Figure 3). Each cell contains a catalyst coated membrane with the active area of 50 cm^2. The bipolar plates were designed with a multiple serpentine channel layout and are made on graphite/polymer composite. The stack is air-cooled and operates with pure hydrogen and air, both fueled at low pressures. The stack was completely instrumented and is currently under test.

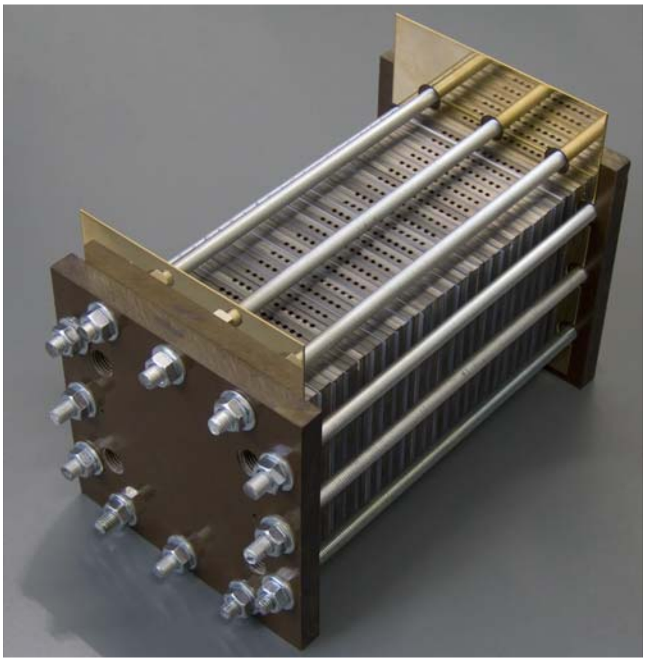

Figure 3 The 25 cells PEMFC system