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INTEGRATED AUTOMATION SYSTEM FOR A PILOT PLANT FOR ENERGY CONVERSION USING PEMFCs

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Based on Hydrogen and Fuel Cells researches and technological capabilities achieved in the National R&D Programs, ICIT Rm. Valcea built an experimental- demonstrative pilot plant for energy conversion using hydrogen PEMFCs. This pilot plant consists of a fuel processor based on steam methane reforming (SMR) process, a hydrogen purification unit, a PEM fuel cells stack (FCS) and a power electronics unit. The paper deals with the dedicated controlling system that provides automated data acquisition, manual or "on line" operational control, gas management, humidification, temperature and flow controls.

Keywords: data acquisition, monitoring-control, gas flow, temperature, pressure, humidity

1. Introduction

In the last decades of the previous century, due to global environmental problems, energy security and supply issues, many studies were conducted to investigate the uses for hydrogen energy and facilitate its penetration as an energy carrier. Subsequently, many industries worldwide began developing and producing hydrogen, hydrogen-powered vehicles, hydrogen fuel cells, and other hydrogen-based technologies. In view of the substantial long-term public and private benefits arising from hydrogen and fuel cells, the European Union and national governments throughout Europe, including the Romanian one, are working towards realising a consistent policy framework preparing the transition to a hydrogen energy economy.

Based on public funds, ICIT Rm. Vilcea developed a research program on energy conversion using fuel cells. An experimental - demonstrator pilot plant of energy conversion using PEMFCs and hydrogen producing via steam methane reforming was achieved in order to investigate the development of small-scale SMR technologies and to permit testing and developing of specific components.

2. The controlling system

The automation system dedicated to the energy conversion pilot plant schematic is presented in fig. 1. It is a 3 levels command and control distributed system.

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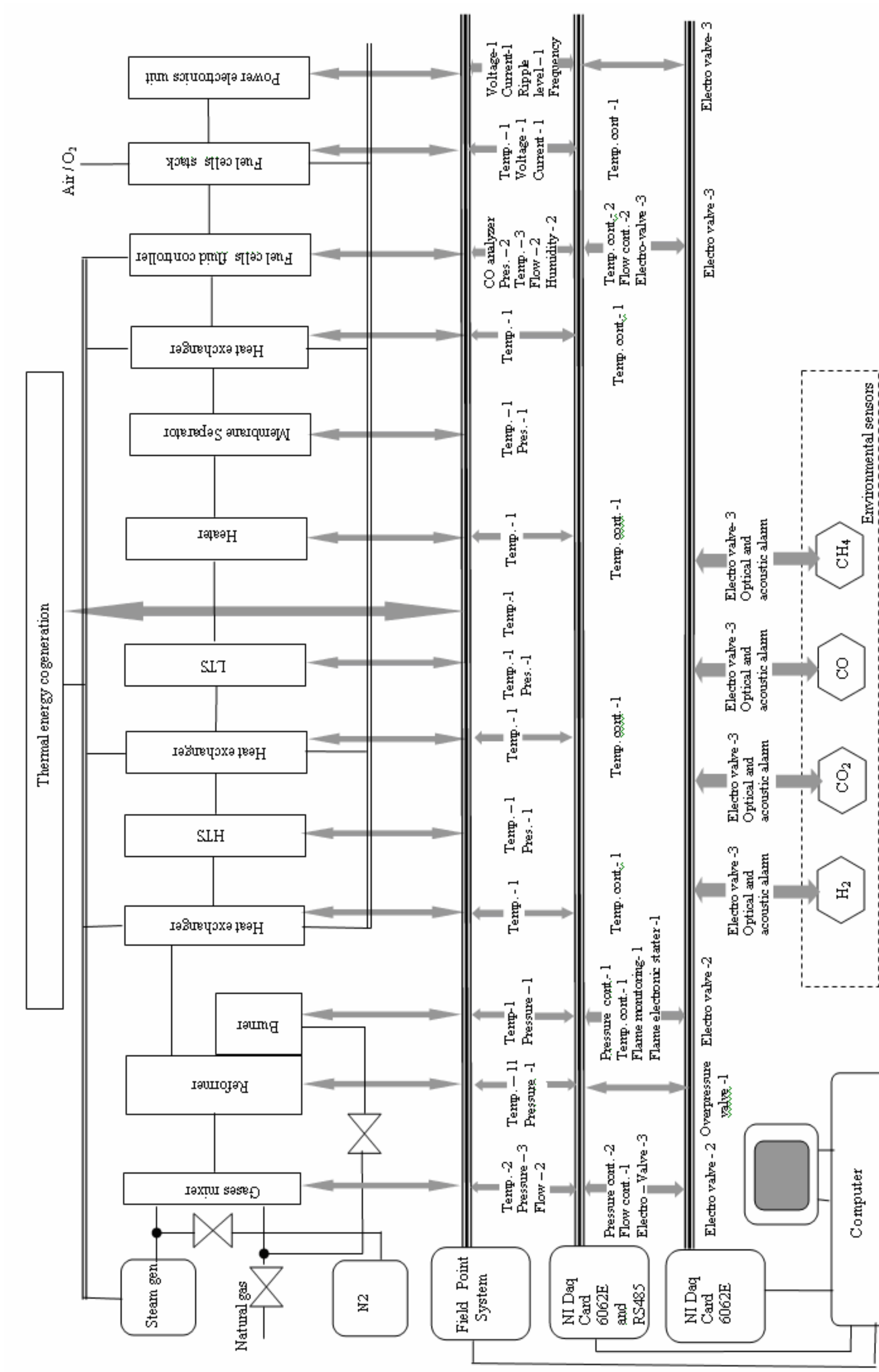

Fig. 1 Schematic of the energy conversion pilot plant controlling system

2.1 Steam methane reforming subsystem

The reformer designed in our institute works at 700º C and 3÷3.5 atm, the steam reforming process occurring on a Ni based catalyst disposed in ten columns, circle distributed.

Before starting out the reforming process, the catalyst is activated maintaining steam/methane mass flow rate of 7/1. At start out, the catalyst is first dried at 500^0C, under nitrogen flow.

The reformer is feed by a mixture of steam and methane having the same inlet pressure- about 3 atm, and the mass flow rate of 3/1, using a mixer. A flow controller maintains the adequate steam/ methane flow ratio in order to avoid coking of the catalyst [1]. The methane flow is about 0.5 Nm^3/h. The flow rate decreasing to 2.8/1 defines an alert situation, and a further decrease in flow rate imposes the shut down of the reforming reaction at a ratio of 2.5/1, by cutting down firstly the methane flow. Electro-valves and temperature sensors are inserted on the mixer input pipes.

The steam methane reforming reaction being endothermic, the required heating is achieved using a methane burner electronically started.

The monitoring parameters of the reformer are pressure and temperatures (11 points- the reformer ensemble and each of the ten columns filled with catalyst). The reformer pressure drop is about 0.6 atm.

Reformer product, the syngas, is composed of hydrogen (50% mol), carbon monoxide (10% mol), carbon dioxide (7% mol), methane (3% mol) and water (30% mol).

2.2 Shift reaction subsystem

The water gas shift reaction is exothermic and occurs in two stages: the high temperature shift (HTS) reaction and the low temperature shift (LTS) reaction.

In the HTS reactor the water gas shift reaction occurs at 550º C, on a Fe_2O_3/Cr_2O_3 catalyst, disposed in three columns, circle distributed. The syngas exiting the reformer is cooled in a heat exchanger to the temperature of 500^0C, then entering the HTS reactor. Its product is enriched in hydrogen (52% mol) and contains also carbon monoxide (7% mol), carbon dioxide (10% mol), methane (3% mol) and water (28% mol). The HTS outgoing gas is cooled again to the temperature of 200^0C, then enters the LTS reactor, which reaction, based on a CuO/ZnO alumina supported catalyst disposed in three columns, circle distributed, occurs at 250^0 C. The LTS product is a mixture of hydrogen (62% mol), carbon dioxide (11% mol), carbon monoxide (1% mol), methane (3% mol) and water (23% mol).

The monitoring parameters of the shift reaction are the reactors pressures (2 points) and temperatures on each reactor and heat exchanger (4 points).

2.3 Advance purification subsystem

After the water gas shift reaction the carbon monoxide content of the hydrogen flow still remains too high to feed the PEM fuel cells stack. High to ultra-high purity hydrogen is needed for the durable and efficient operation of PEM fuel cells. Impurities are believed to cause various problems, including catalyst poisoning and membrane failure. As such, an additional process step is required to purify the hydrogen carbon monoxide content to the appropriate level.

A Palladium membrane separator working at 450^0C and 1.5÷1.8 atm purifies the water- gas shift reaction product. The gas entering the separator is heated in an electric heater with temperature controller. The purified hydrogen exiting the permeator is cooled in a heat exchanger to 25 ÷ 30^0 C. A carbon monoxide analyzer cuts the stack feeding at carbon monoxide concentration greater than the imposed limit.

The monitoring parameters of the advanced purification subsystem are the membrane separator pressure (1 point), temperatures on membrane separator, heater and heat exchanger (3 points) and carbon monoxide level in the exiting hydrogen flow.

An electro- valve controlled by the safety system exhausts the hydrogen at risk.

2.4 PEM Fuel Cells Stack

The hydrogen proceeded from the purification unit or from a cylinder feeds the anode side of a 1 kW PEM fuel cells stack PEMFCS [4] or, via an electro-valve, a hydrogen storage unit, when the stack is shut down. The cathode side of the fuel cells stack may be fed with air, using a blower, or with oxygen from a cylinder.

The PEMFCS fluids management schematic is presented in figure 2.

In this figure, NV_i are needle valves , VR_i are 3 way valves, R_i are manual valves, TC_i are temperature controllers, P_i are pressure sensors, RH_i are humidity sensors and T_i are temperature sensors.

The feeding of the PEMFCS is made via a heat exchanger for water cooling and a flow control valve, NV_7. Water temperature is measured on the cooling system inlet and temperature and pressure on the cooling system outlet. The R_6 valve controls the re-circulated water pump load especially when the water flow is low (namely at start, until the fuel cells stack reaches the temperature of 80^oC). Also, the water cooling system ensures the supplement of water level in the humidifiers.

The heating sub-system of the fuel cells stack includes a resistive heater and a temperature controller. The heater has the role of minimizing the settling time of the stack, especially when the ambient temperature is low. An 8 input thermometer offers the possibility of measuring the temperature on each cell of the stack.

On the power generation system of the PEMFCS, voltage and current measurements are carried out. In the system there is variable load resistance (0,6 Ω ÷100 kΩ) of 1,5 kW power.

Current measurement is done by measuring the voltage onto a calibrated shunt resistance (0.0001 Ω/100 A), comparable as range with the internal resistance of the fuel cells stack, so will not affect the Voltage-Current density characteristic in the ohmic loses zone. Those two voltmeters have input impedance higher than 10GΩ.

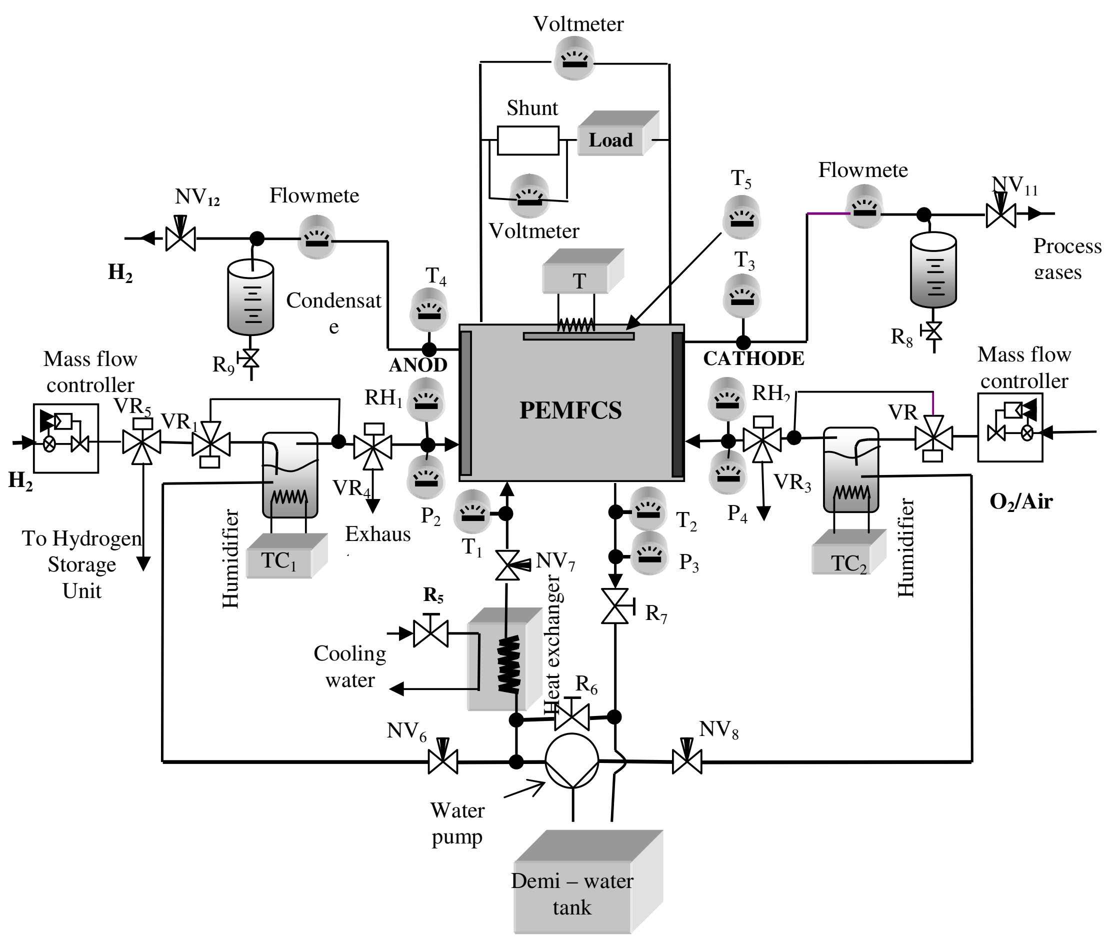

Fig. 2 Fuel cells stack fluid management schematic

All the testing system parameters measurements (temperature, pressure, flow) [5] are made both in local mode and with transmitter, so the acquisition interface allows data collecting by a PC.

Both anode and cathode water collecting systems consist of a condensate trap allowing the water volume measuring and a manual valve (R_9 and R_8 respectively) serving for trap emptying and/or water samples assaying. The need for the anode water collecting arises from the observed phenomena of water transport by diffusion through membrane, from cathode to anode. Measuring the cathode resulted water volume provides useful input data for energy cogeneration subsystem design.

The fuel cells stack gas management is made by controlling gas flow (2 points), pressure (2 points), temperature (2 points) and humidity (2 points). Fuel cells stack temperature is also monitored (8 points).

Both cathode generated water and that proceeded from heat exchangers enters the thermal cogeneration system.

The generated electricity is stored, via a DC-DC boost converter [6], on lead-acid battery pack with ultra-capacitors system controlled by fuzzy logic in order to provide an optimum transfer characteristic when connecting batteries to the low level cc output (60 V) of the fuel cells stack.

An inverter system provides the electrical power supply for an ac dynamic load, assuring the power spectral quality.

3. Controlling system architecture

All working parameters of the plant are input data of a command and control distributed system (DSC). A Field Point programmable system [7], represents the DSC's 1st level for temperature, pressure, flow, humidity, voltage and current data acquisition.

One of the advantages of the FieldPoint system is that new sensor modules can be easily added and the installation can be configured using a simple software tool. An additional advantage is that since each FieldPoint device can function independently, a single computer may be used to acquire data from many such distributed devices. The host computer accesses data from a FieldPoint sensor bank by periodically polling the corresponding network interface module. The acquisitioned data are processed in the PC.

A user interface allows data reading and modules and sensors installing conditions checking, in order to avoid communication errors. The graphic interface is realized using Microsoft Visual Basic 6.0 and includes a series of visual elements such as: selection buttons, emergency illuminated buttons, displaying panels, I/O blocks, diagrams. An image of a print screen of the SMR monitoring program is presented in fig. 3.

Temperatures on hydrogen generator are measured using mineral insulated type K thermocouples with stainless steel sheath sensors, and those on fuel cells stack, with platinum resistance thermometer Pt100.

The temperatures and flows controlling units represents the 2nd level of the DSC. This unit are coupled to the PC via a RS 485 serial interface and a NI Daq card 6062E.

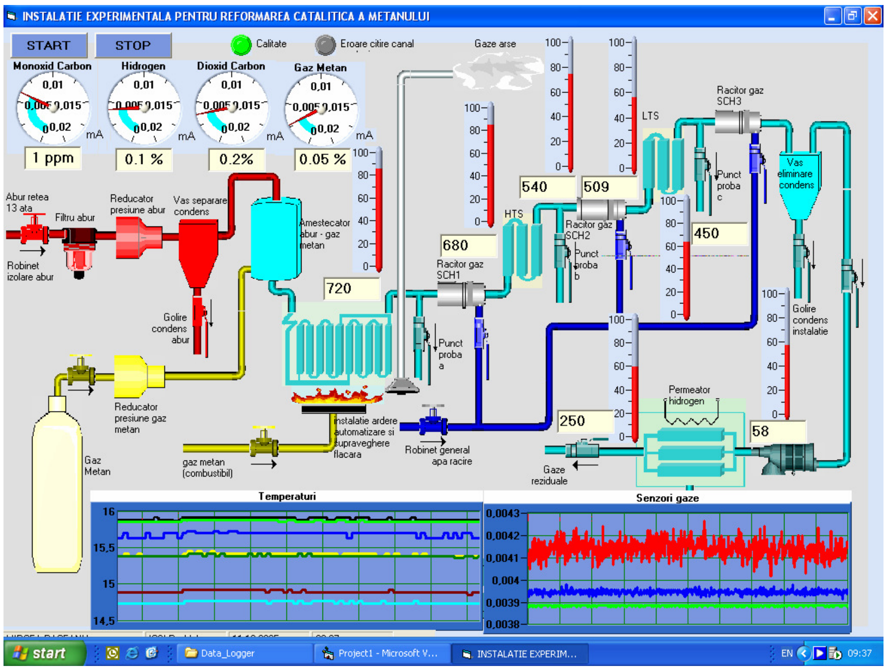

Fig. 3 Print screen of the SMR monitoring program

Temperatures control, except that of the reformer, is achieved via eight Honeywell Controllers, which are economical, microprocessor – based temperature controllers, with solid state relay output controller. The temperature sensors, except that one of the fuel cells stack, are mineral insulated type K thermocouples with stainless steel sheath.

The reformer temperature control is realized by controlling the burning methane flow using a clapper- valve driven by a stepping motor controlled by a servo-controller. The methane pressure is maintained constant in order to make the reformer temperature control more accurate. The burner has double safety system: against flame extinction and main supply shut down: the flame monitor drives an electro-valve to cut the inlet methane flow at flame extinction and a shut off valve realizes the same action at main supply shut down.

Pressures control for the inlet natural gas and steam is realized with hand acted pressure regulators with bleeder.
The safety system monitors the experimental demonstrative pilot plant against flammable (hydrogen and methane) and toxic (carbon monoxide and carbon dioxide) gas pollutants, providing both optical and acoustic alarms and starting the shut down procedure. This system represents the 3rd level of the DSC.

A dedicated software package based on Microsoft Visual Basic 6.0 displays successively the three levels state, accessing automatically the correspondent frame, if an alert or alarm situation is detected. It provides the possibility of both automatic and manual controlling of working parameters.

4. Conclusion

The experimental- demonstrative plant for energy conversion using PEMFCS built at ICIT Rm. Vilcea was conceived as an experimental facility for joint RTD activities of the Romanian entities in the area of hydrogen and fuel cells.

The experimental- demonstrative character of the plant for energy conversion using PEMFCs imposed the great number of surveying parameters and the complexity of control loops, because the plant was achieved in order to be a flexible utility allowing the possibility of developing researches both in steam-methane reforming (improving reforming efficiencies, identifying more durable reforming catalysts and developing advanced reforming , shift and purification technologies), and PEM fuel cells (improving FC performances by higher CO tolerance, low pressure air supply, low humidification, and reducing costs by lower Pt catalyst loading or alternative catalyst).

Energetic efficiency issues are not directly a subject of this experimental-demonstrator plant as a whole, but improvements in its components performances, reliability and efficiency will result from the developed researches

4. References

[1] J. Larminie, A. Dicks – Fuel Cell Systems Explained - Second Edition, J.Wiley&Sons, N.Y., 2003, p.238-253
[2] A.D. Little, Multi- Fuel Reformers for Fuel Cells Used in Transportation – DOE/CE/50343, 1994
[3] C. Stratula, s.a. - Modelarea teoretica a procesului de reformare catalitica a gazului metan / Theoretical modelling of methane cathalitic reforming process/ – Ed. Tehnica, Bucuresti, 2001, p.101-162
[4] S.Giddey, s.a., Design, Assembly and Operation of Polymer Electrolyte Membrane Fuel Cells Stacks to 1 kW Capacity – J. Of Power Sources,125, 2004, p.17-35
[5] S. Caux, J. Lachaize, M. Fadel, P. Shott, L. Nicod: Modelling and control of a fuel Cell System and Storage Elements in transport application in Journal of Process Control 15/2005