

Development of the Energy Management System to Control a Hybrid Power Generator

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Introduction

- CIEMAT – CSIC Fuel Cells Group
 - Fuel Cells and Integration Systems Unit –CIEMAT
 - Fuel Cells Unit-ICP-CSIC
 - The group works in Fuel Cells since 1994
 - Covers PEMFC, MCFC and SOFC. Catalytic development and hydrogen production
 - Works in development of components (mainly electrodes and MEAs)
 - Works in testing of cells (single cells and stacks)
 - Develops integrated systems and applications

Integrated systems

■ Experience

- Photovoltaics-H₂-Fuel Cell:
FIRST Project
- Photovoltaics-Wind
Turbine-Fuel Cell: Projects:
AEROPILA, PROFIT-Aragon, ENERCAM
- Biogas-Fuel Cell: Projects:
EFFECTIVE, AMONCO, IRMATECH,
PROFIT-EMUASA, ENERCAM, CENIT
SOSTAQUA



GELSHI: Objectives

Generación de Energía Limpia mediante Sistemas Híbridos

- Acronym in Spanish of Clean Energy Management through Hybrid System
- Integrating different renewable energy sources
- Developing an effective Energy Management System that controls the integrated system
- Applied as uninterrupted, grid isolated, power generation

Components

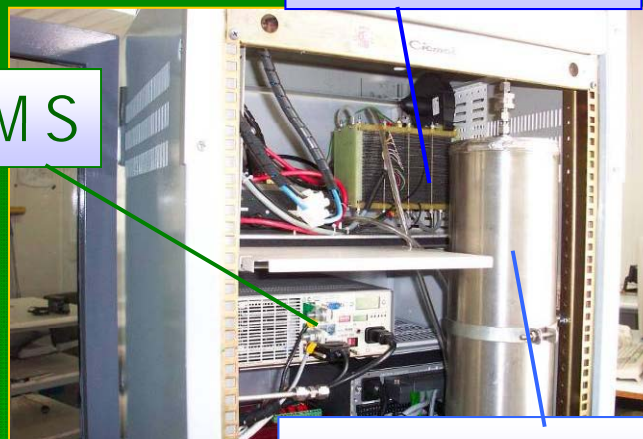
Photovoltaic panel (PV)



Data acquisition system

Battery (inside)

EMS



Fuel cell (FC)

Hydride container

Wind turbine (WT)



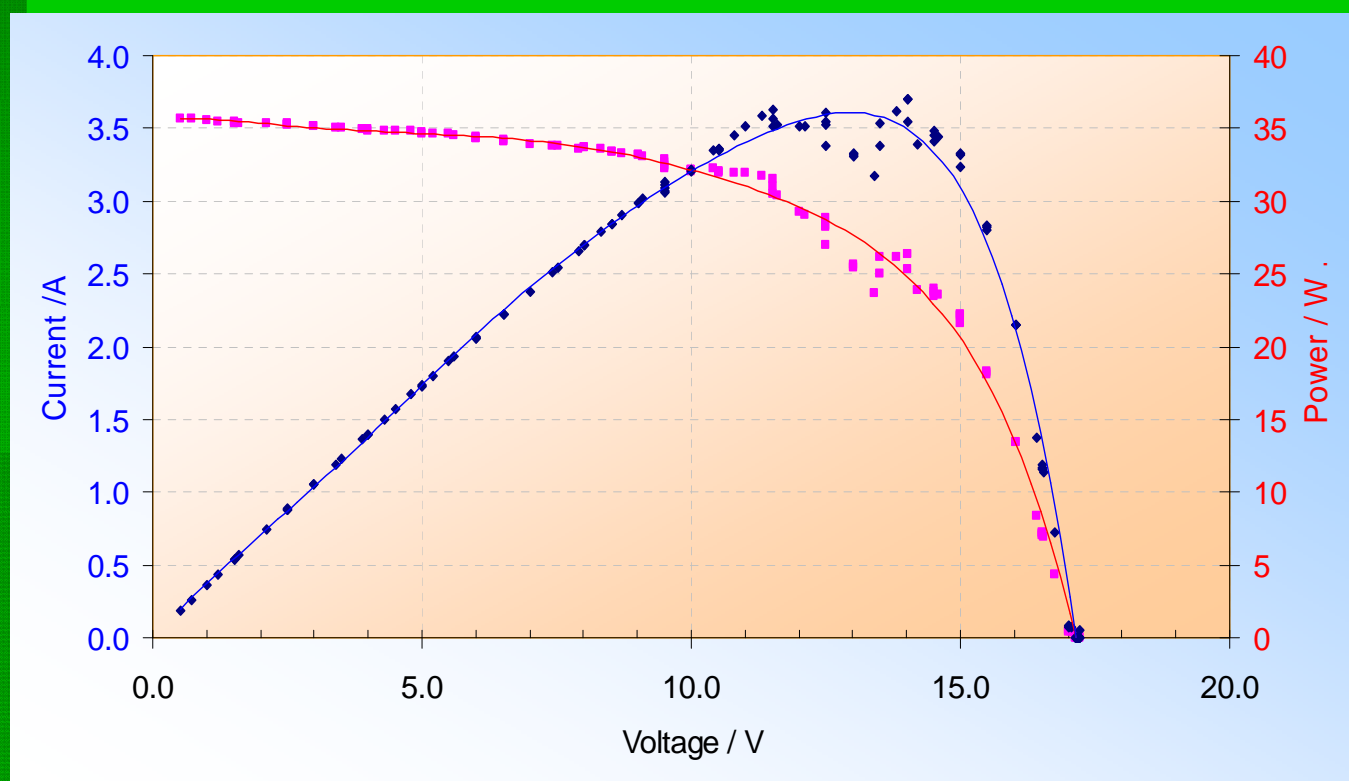
Components: Photovoltaic panel

- Isofoton monocristaline silicon
- Open circuit voltage 18 V
- Current at short circuit 8A
- Peak power of 94 W_p (75 W maximum registered under working conditions)
- Orientation: South, inclination 50°



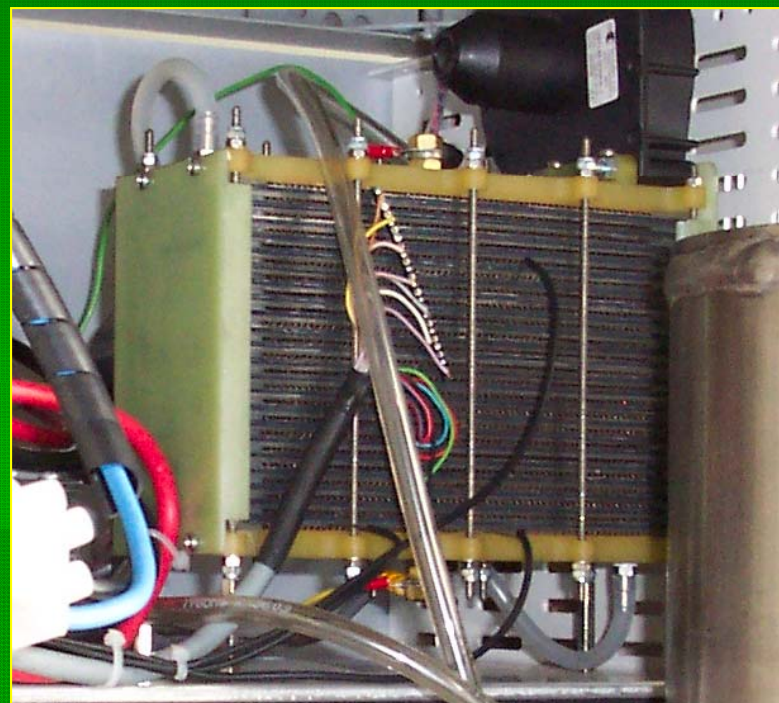
Components: Photovoltaic panel

- Power curve under one day working conditions



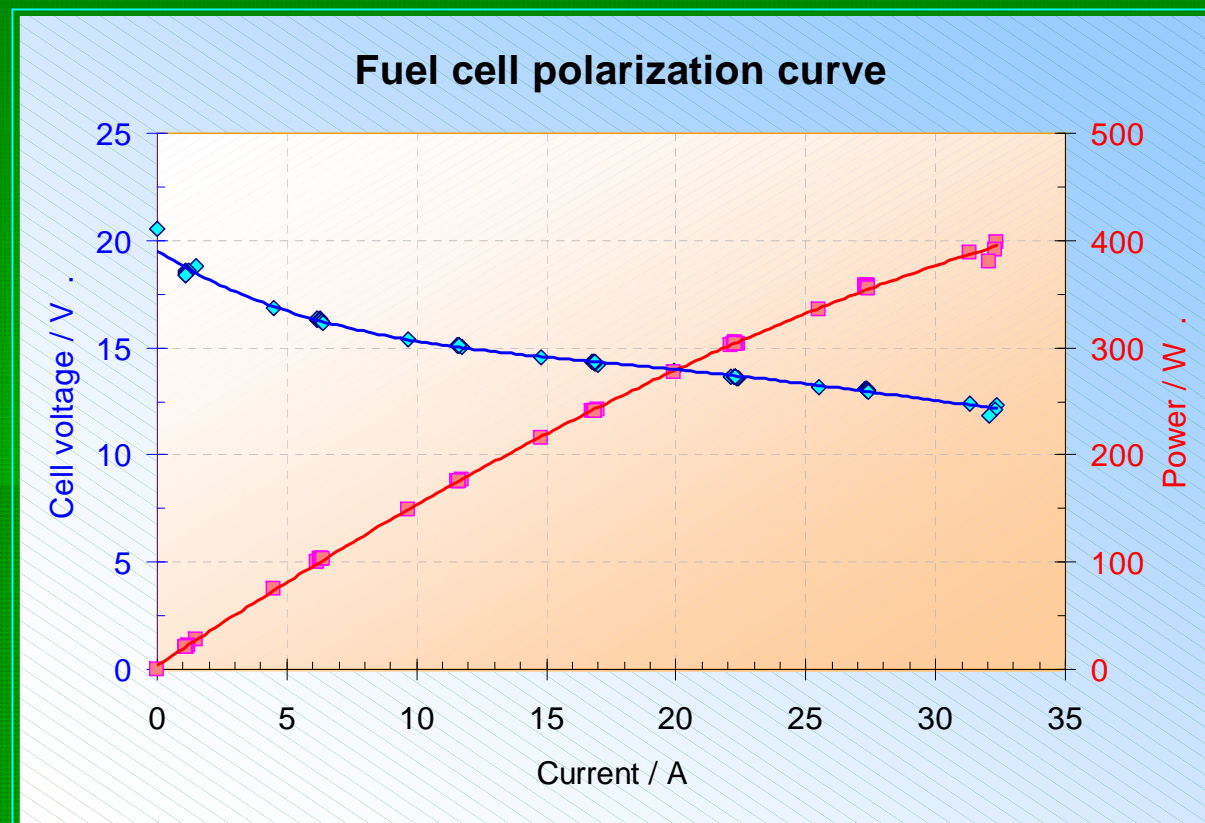
Components: Fuel cell

- MES-DEA PEMFC
- Number of Cells: 22
- Maximum power: 500 W
- Voltage: 21 – 13 V
- Maximum current: 30 A
- Air forced refrigeration
- Graphite bipolar plates
- Channelled cathode plate
- Carbon paper as gas diffuser



Components: Fuel cell

- Polarization curve under working conditions



Components: Wind turbine

- Air X Marine
- Diameter: 1.15 m
- Start-up wind speed: 3 m/s
- Max wind speed: 50 m/s
- Voltage: 12V
- Power capacity: 400 W at 12.5 m/s



Components: Battery

- Sealed type stationary lead-acid storage battery
- Voltage: 12V
- Power capacity: 65 Ah



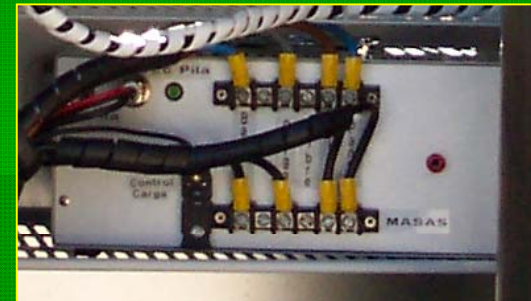
Components: Hydrogen storage

- Developed at the Catalysis Institute (CSIC)
- Metal hydride system
- Alloy of La-Ce-Ni-Al-Sn
- Capacity: 10 Nm³ of hydrogen at 30 bar



Components: Energy Management System

- Developed by our Fuel Cell Group
- Based on
 - Software: Labview application
 - Hardware: measuring instrumentation, switches, data logger
- Management of power generation and consumption
- Control of components on/off
- Control parameters:
 - Power generation rate (solar, wind, fuel cell)
 - Battery state-of-charge (voltage)
 - Power consumption (electronic load)



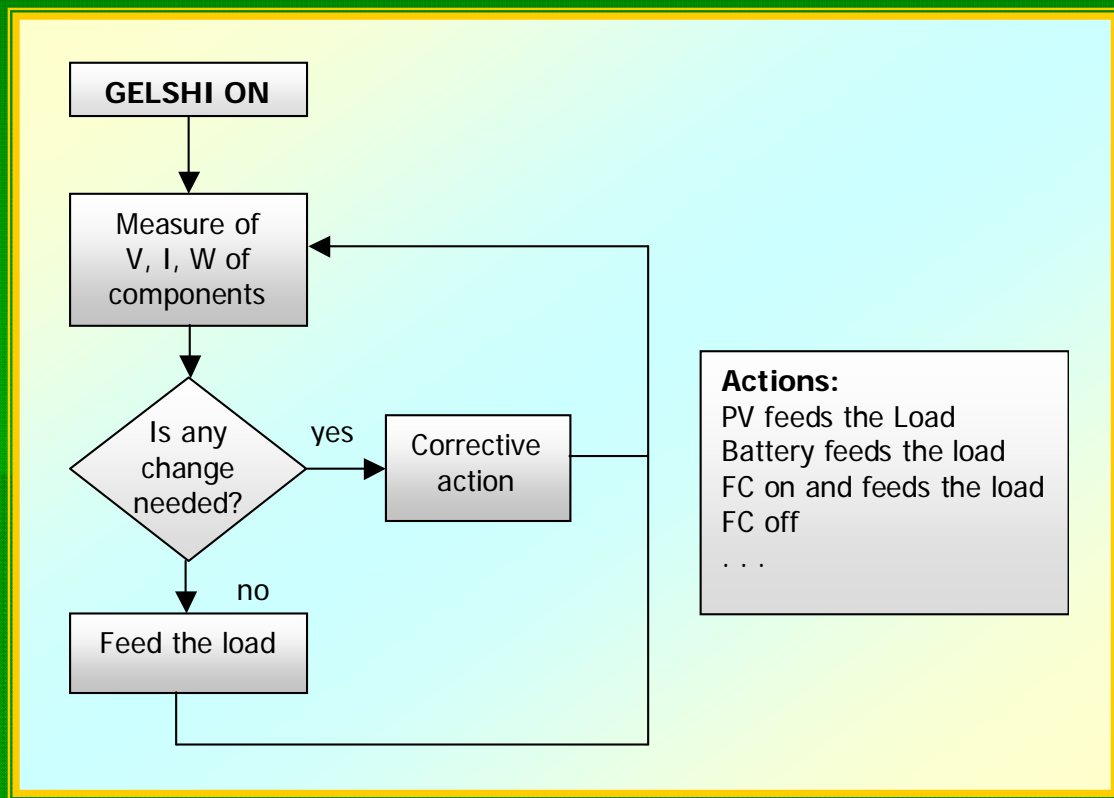
Components: Data acquisition

- Continuous data monitoring
- Analysis of power generation and consumption
- Multiple data storage:
 - V, I, W of each element (PV-WT-FC-Bat)
 - FC operating data: cell voltages & temperatures
 - Load consumption

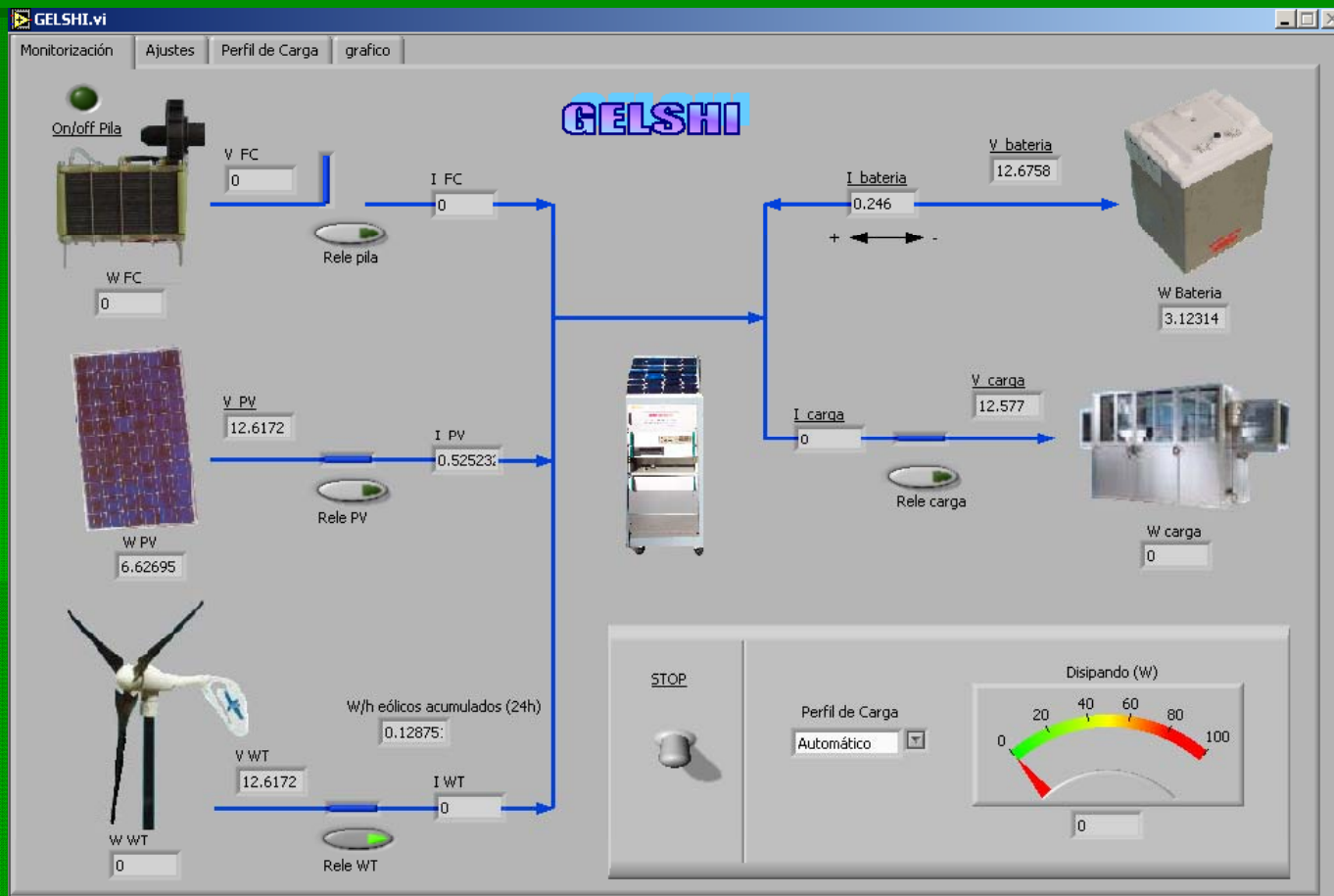


EMS development, control and data acquisition (EMS-DA)

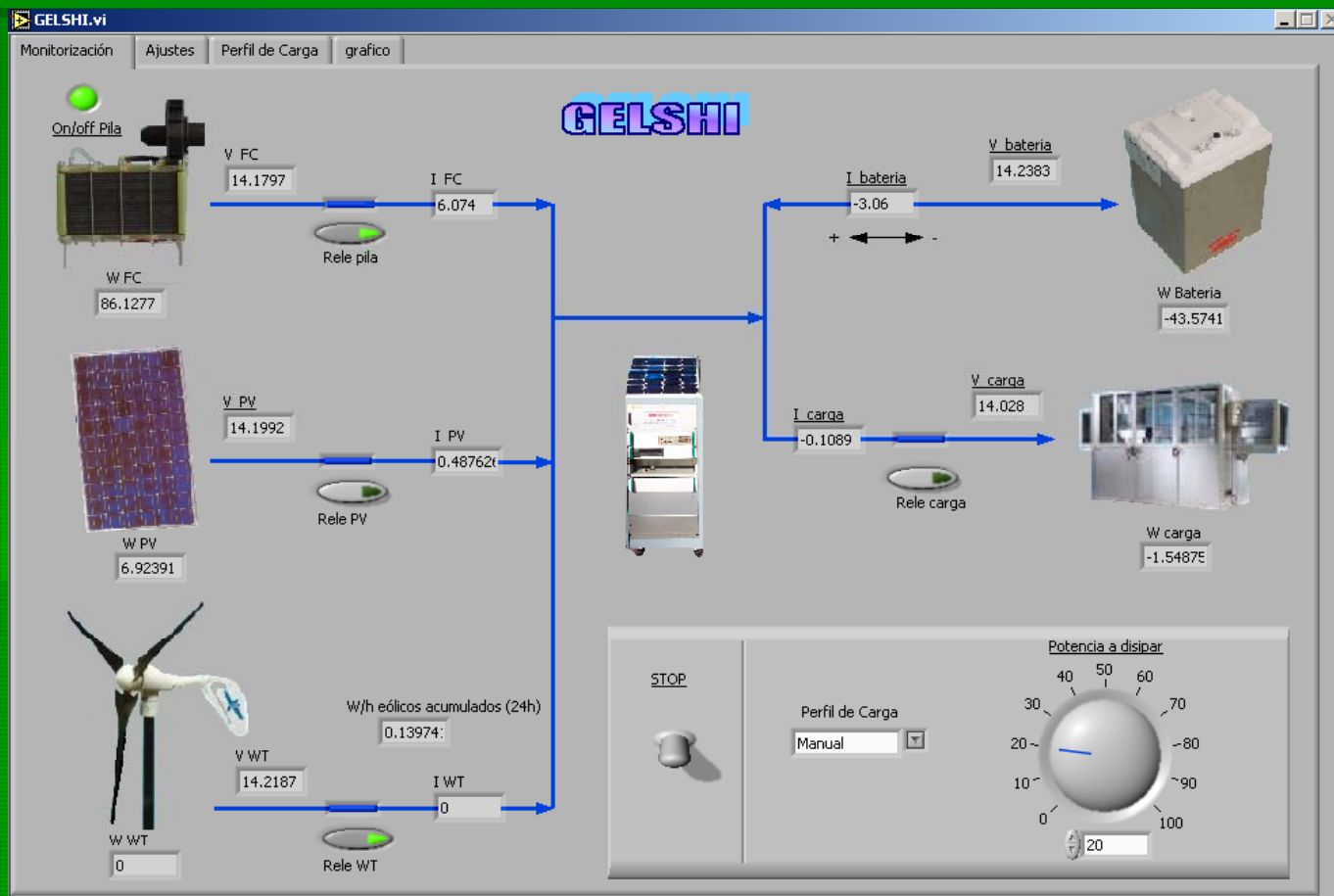
- Flow diagram and control loops



EMS development, control and data acquisition (EMS-DA)



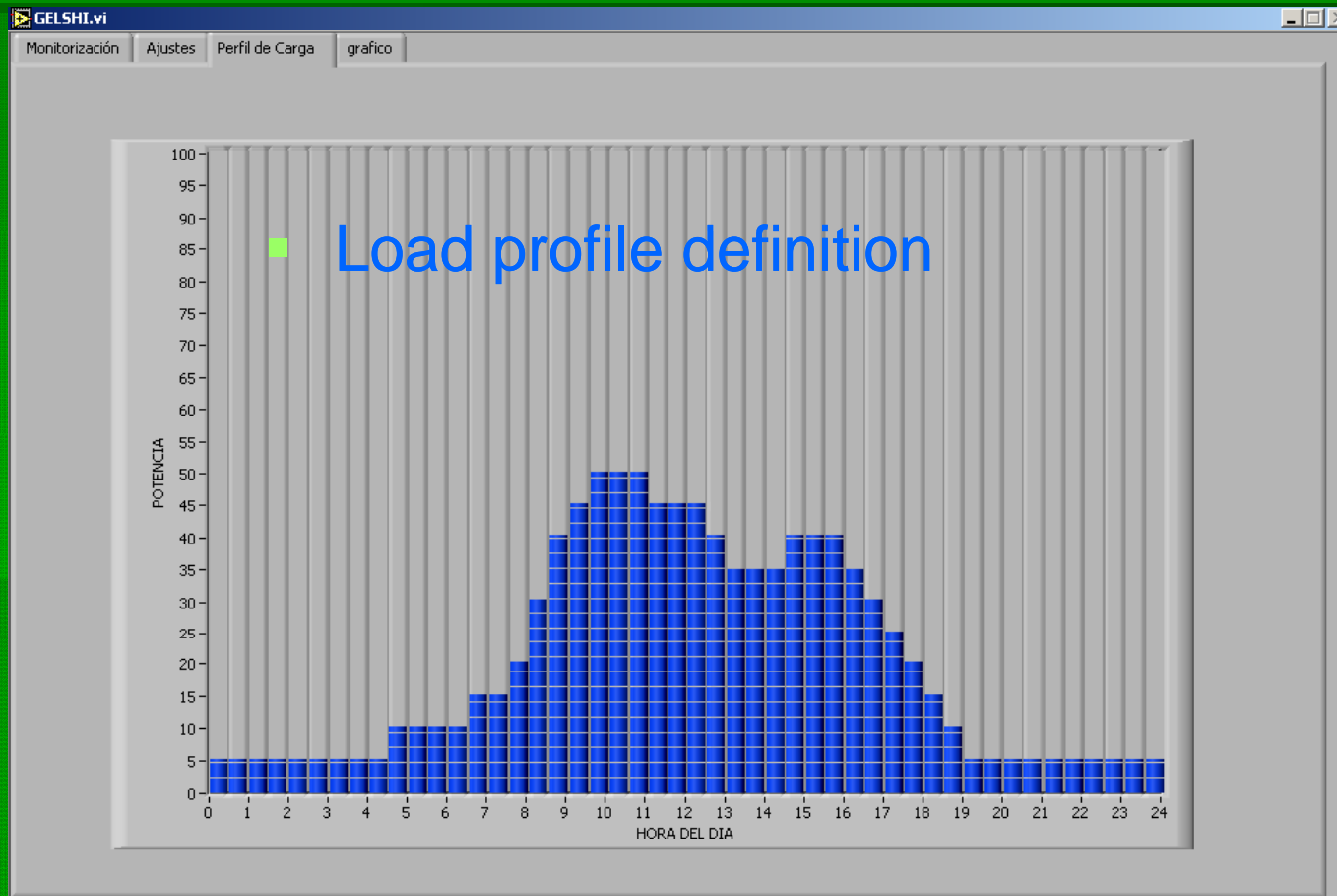
EMS development, control and data acquisition (EMS-DA)



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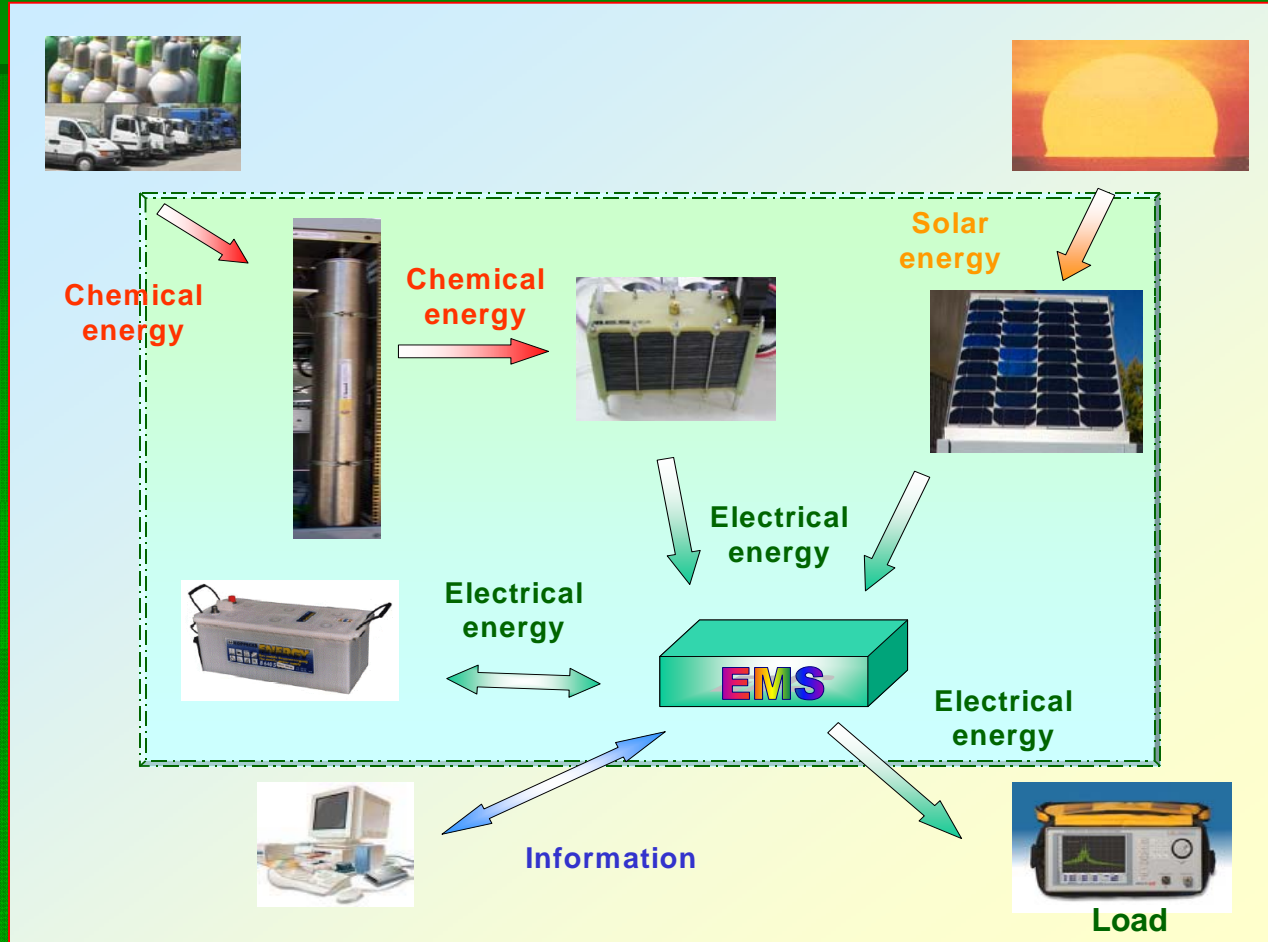
EMS development, control and data acquisition (EMS-DA)



Operation modes

- Hydrogen production mode
 - The system optimises the energy consumption as a function of energy availability: of interest for continuous hydrogen generation
- Load profile
 - The energy consumption follows a profile (constant or variable).

Operation mode. Hydrogen production mode

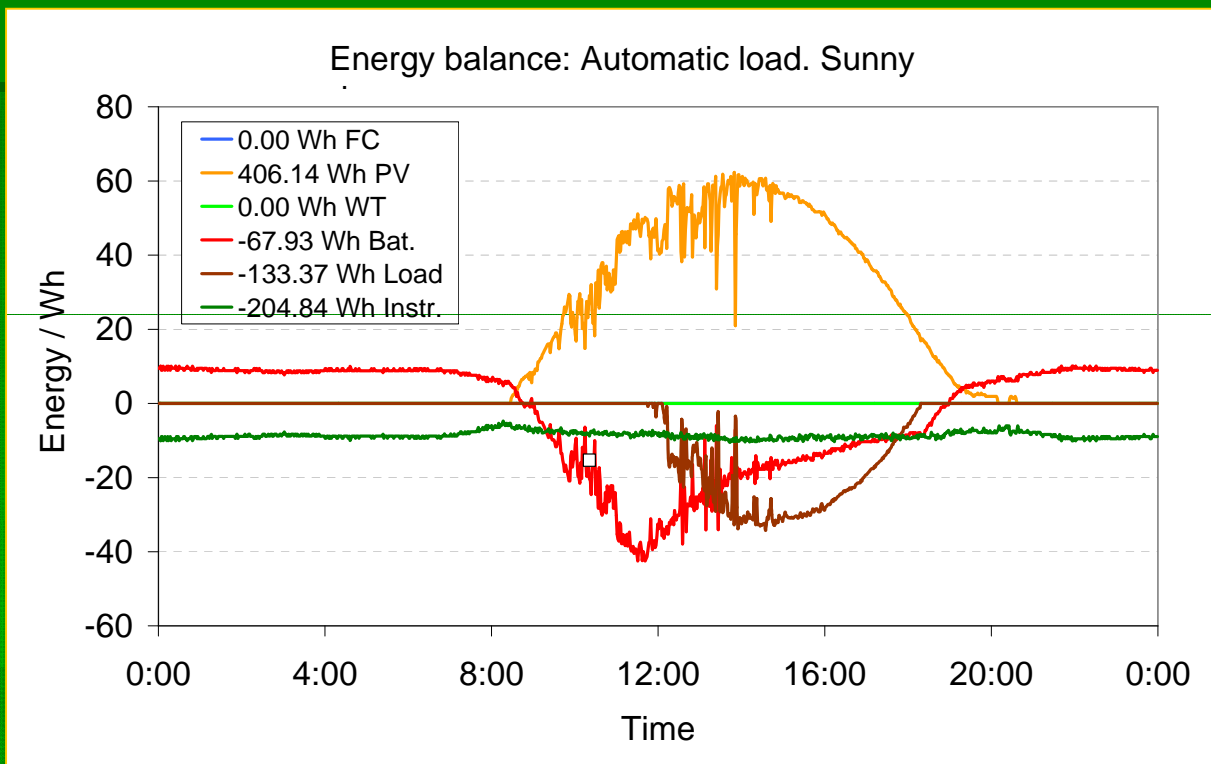


Operation mode.

Hydrogen production mode

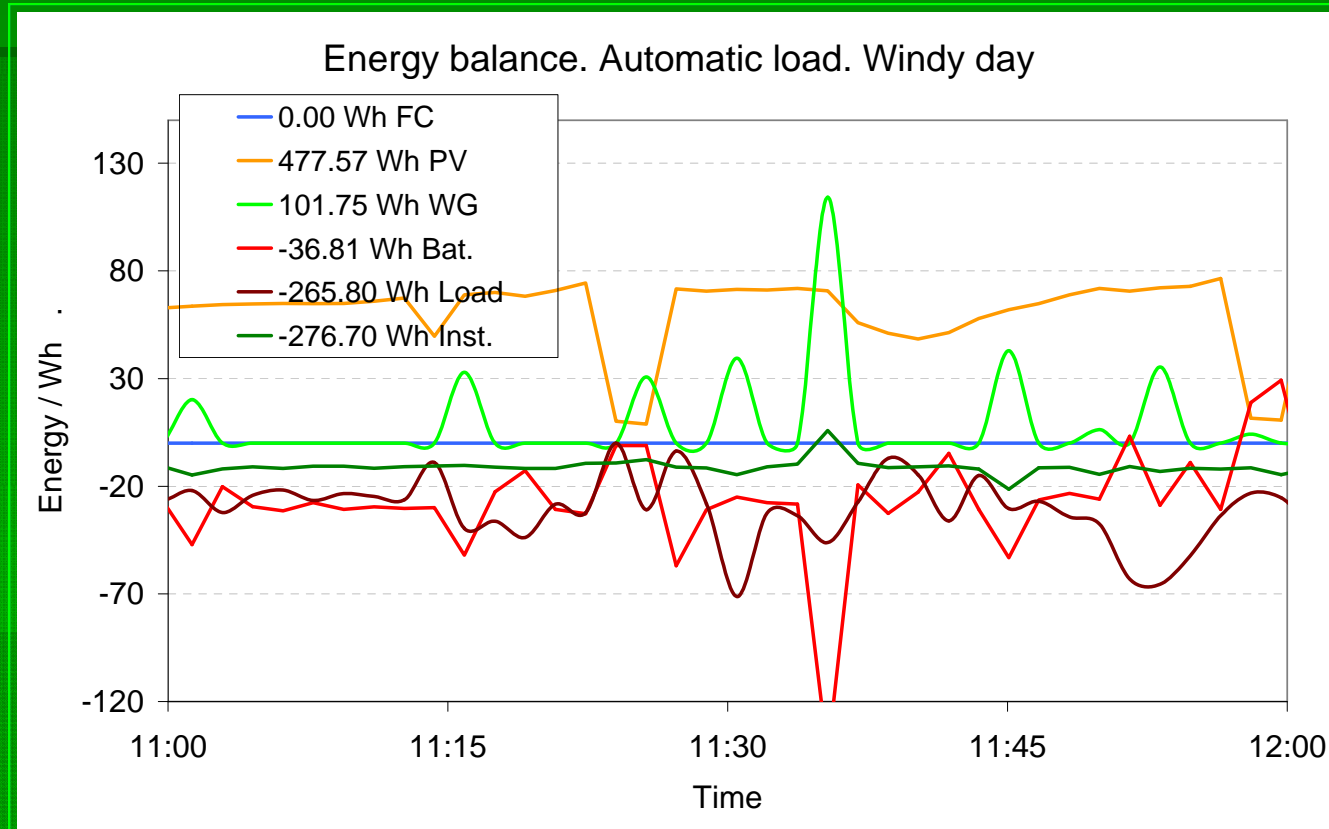
- PV, WT generates energy along light/windy hours
- Battery generates or stores electricity as required
- FC starts up or shuts down to supply basic system consumptions
- EMS controls load consumption

Operation mode. Hydrogen production mode



- Along the night the battery supplies the needed energy for system basic consumption
- Along the day photovoltaic panels supply excess energy
- The EMS maintains the battery SOC over an optimum value and supply the excess to the load

Operation mode. Hydrogen production mode



- Simultaneous PV and WT generation (1 day – 1 hour).

Operation mode.

Hydrogen production mode

Day	FC h	PV h	WT h	Battery h	Load h
1	0,00	6,64	0,00	15,36	0,00
2	0,00	1,17	0,24	23,80	23,83
3	0,00	7,57	0,11	23,57	5,21
4	1,04	8,20	0,41	14,01	3,33
5	0,00	7,20	0,00	22,91	0,00
6	0,00	9,40	0,00	23,73	3,85
7	0,00	9,81	3,00	23,42	6,76
8	0,00	10,19	3,84	23,38	6,19
9	0,00	10,79	0,19	23,27	5,67
10	0,00	11,01	0,00	23,59	6,50
11	6,60	11,66	0,00	23,08	8,32
12	0,00	11,18	0,00	23,57	6,20
13	0,00	11,81	0,00	23,41	5,31
14	0,00	12,43	0,05	23,41	2,71
15	0,00	10,66	0,00	22,86	0,00
16	6,88	11,60	0,05	22,99	0,32
Total	14,53	151,30	7,89	356,35	84,20

- Hours of operation

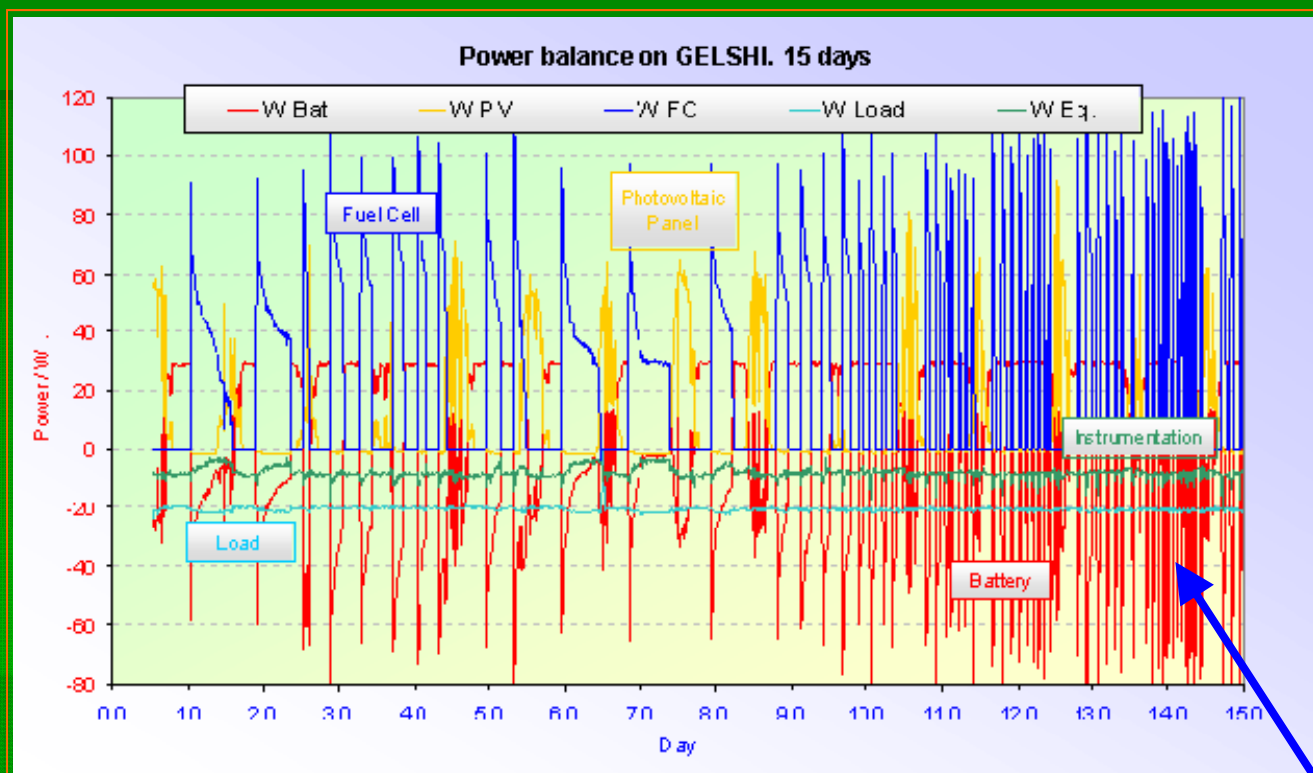
Operating mode.

Hydrogen production mode

Day	FC (Wh)	PV (Wh)	WT (Wh)
1	0.00	135.47	0.00
2	0.00	4.04	2.73
3	0.00	287.12	0.14
4	208.24	224.57	1.68
5	0.00	60.31	0.00
6	0.00	364.59	0.00
7	0.00	477.57	101.75
8	0.00	454.68	112.43
9	0.00	452.66	3.98
10	0.00	472.01	0.00
11	318.86	455.74	0.00
12	0.00	388.50	0.00
13	0.00	398.41	0.00
14	0.00	317.81	0.60
15	0.00	176.44	0.00
16	232.83	167.04	1.01
Total	759.92	4836.96	224.31
%	13.05%	83.09%	3.85%

- Energy generation
- Photovoltaic panels are the main generators
- Fuel cell contributes few times to maintain the system working.
- Wind turbine generates only a few windy days

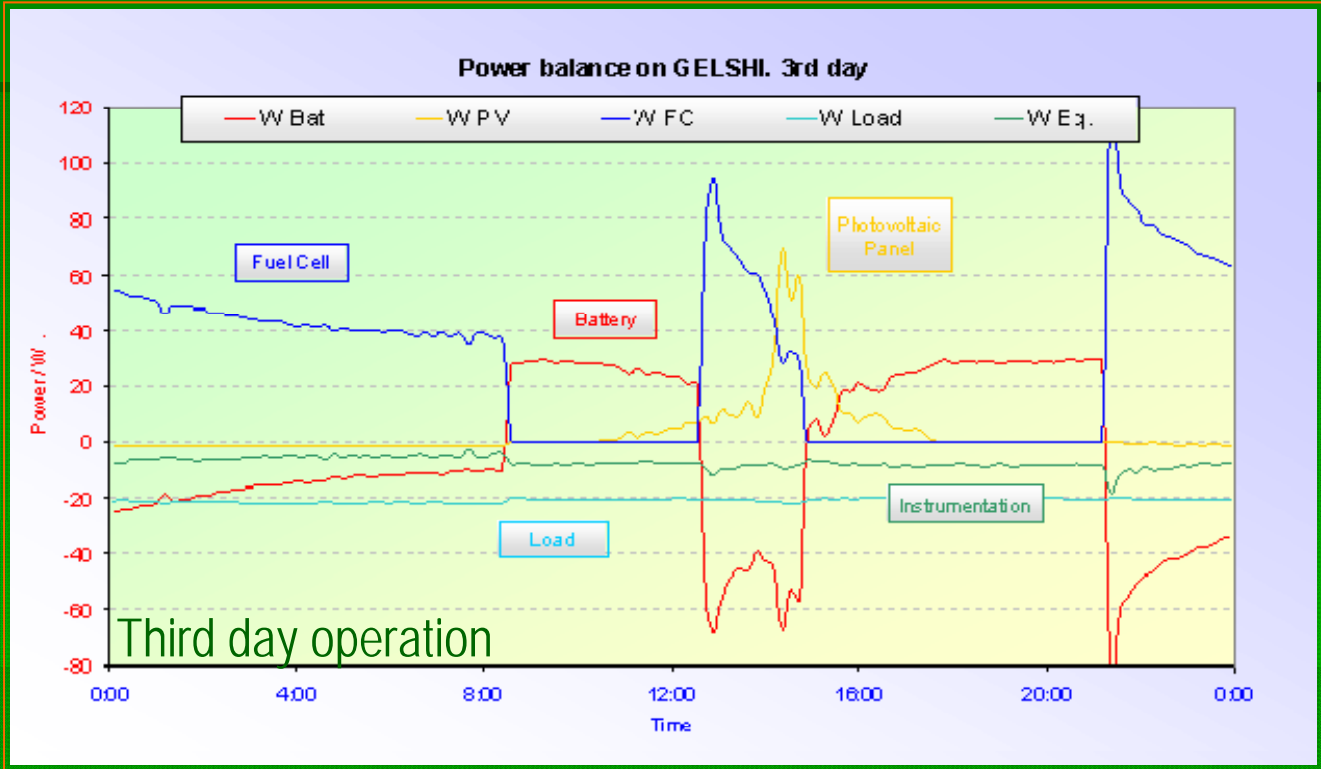
Operating mode. Constant load



more frequent cycles due to battery failure

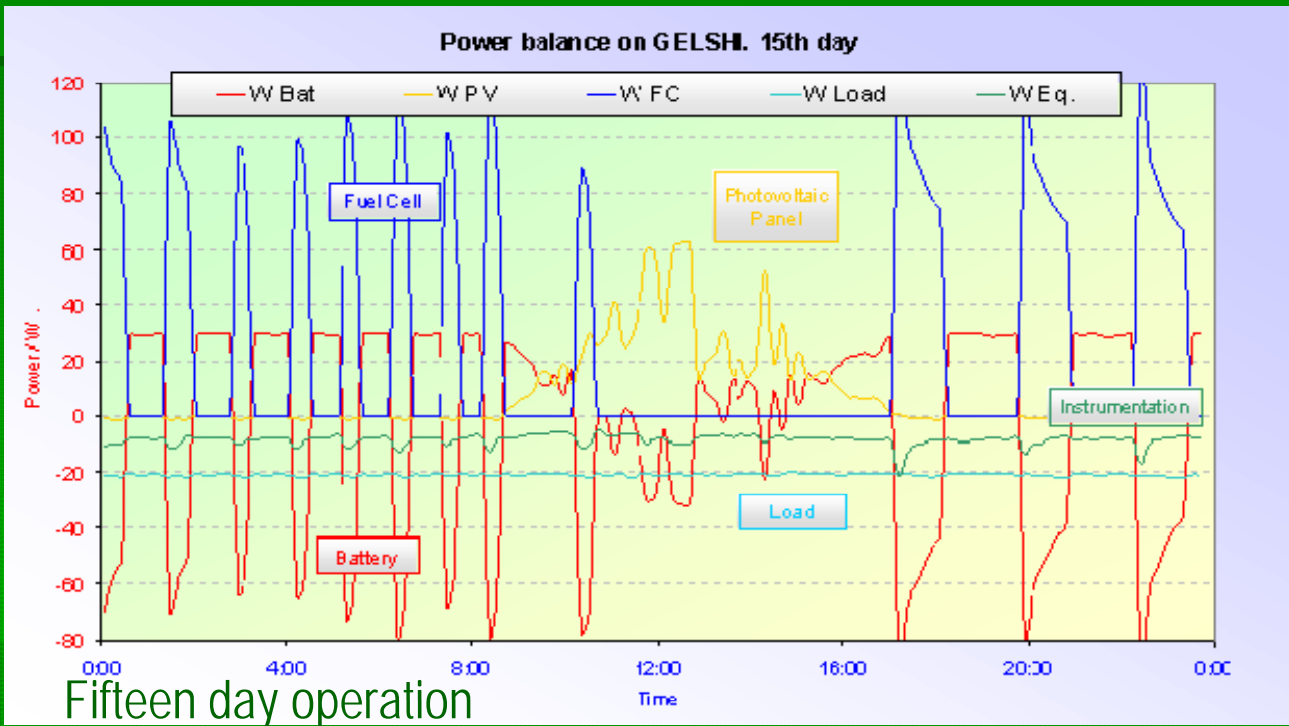
- Series of fifteen working days
- Constant load of 20 W
- Photovoltaic panel and fuel cell as electric generators
- Battery as energy buffer

Operating mode. Constant load



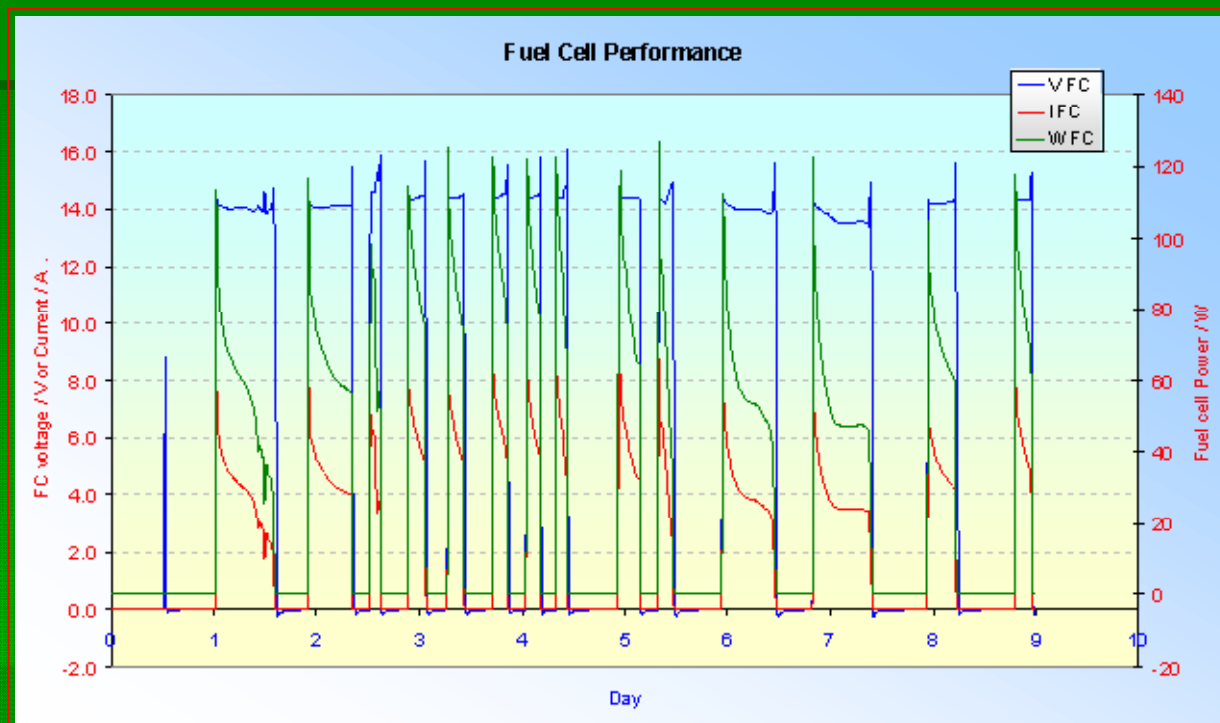
- FC and photovoltaics generation (no WT)
- Uninterrupted load consumption

Operating mode. Constant load



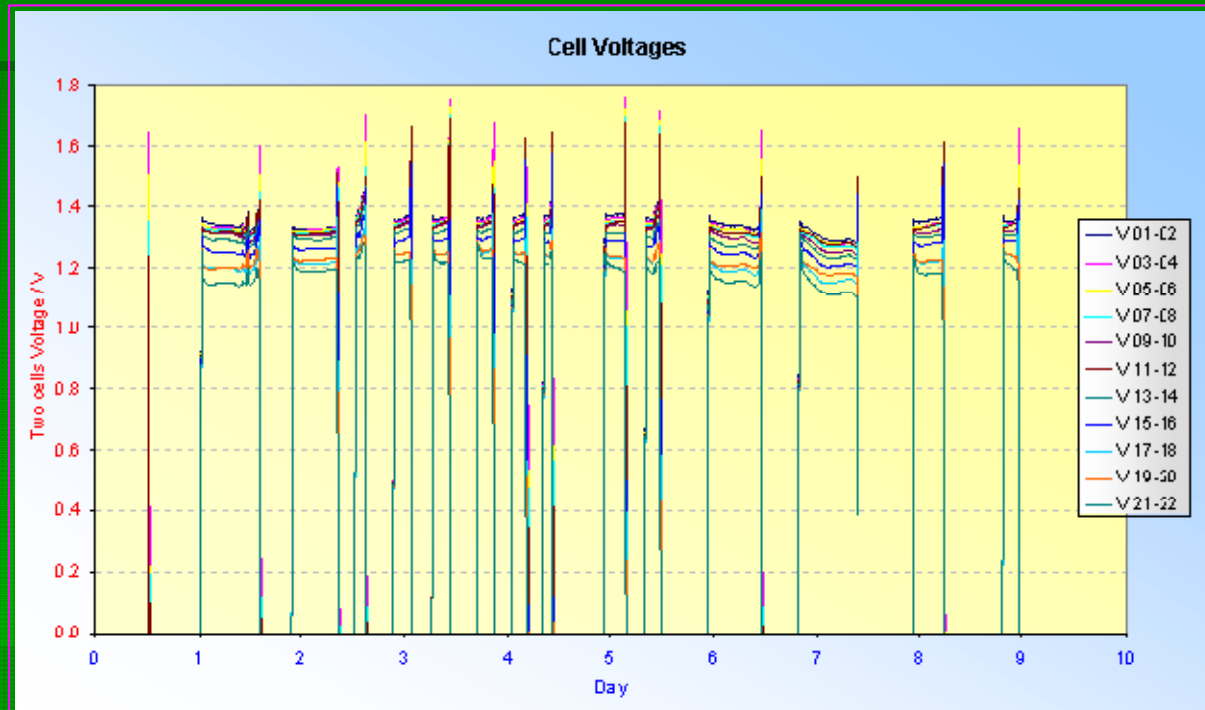
- Battery charge cycles overnight (by FC)
- Mixed battery charge, by FC and PV, during day

Fuel Cell operation



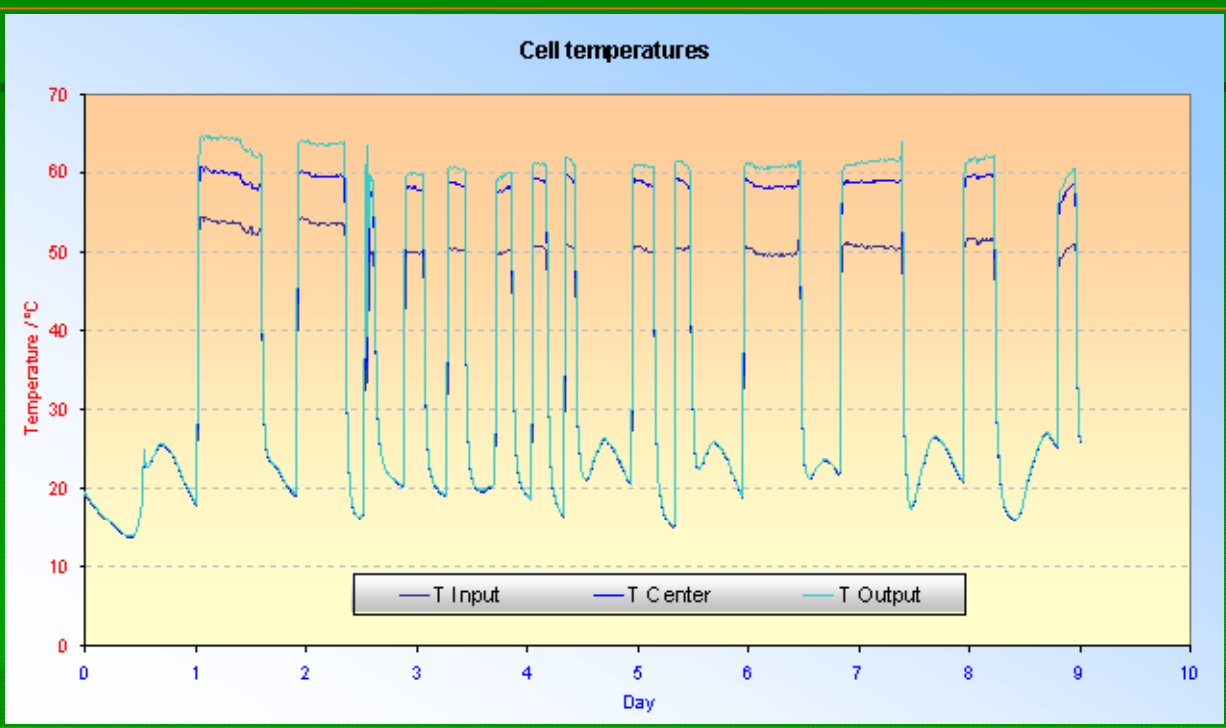
- 500 h operation during 6 months
- 1000 on/off cycles

Fuel Cell operation



- Bottom cells have some inferior performance
- Other cells maintain its performance near the initial

Fuel Cell operation



- Cell temperatures: 50 - 70 °C

Final remarks

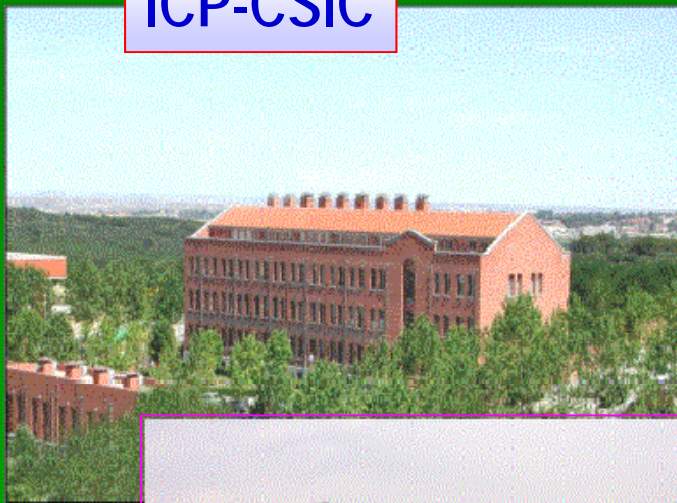
- A power generation system based on renewable energies and fuel cell is presented working under two different modes: automatic generation and constant load
- The EMS developed assures proper working conditions depending on the operation mode
- The system has been operated during 1 year at both operating modes
- Major failures are encountered in the battery and some cells of the FC stack

Fuel Cell Group

CIEMAT



ICP-CSIC



*Thank you for
your attention*