UNIVERSITA' degli STUDI di ROMA
TOR VERGATA

Performance analysis of a hybrid power system for a stationary off-grid load.

Gennaro Criscuolo

Supervisor: *Ing.Vincenzo Mulone* *Co-Supervisor*: *Ing. Giacomo Bruni*

30 October 2013

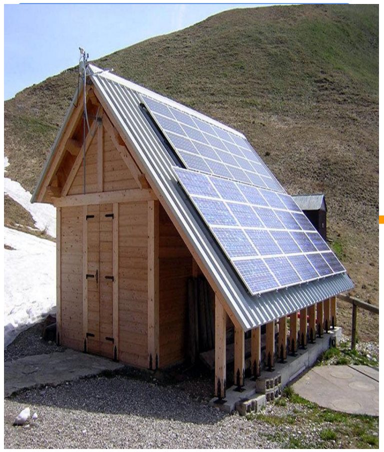
Engineering Sciences

Università di Roma Tor Vergata

Context

Renewable Energy

Electrical energy supply for off-grid application

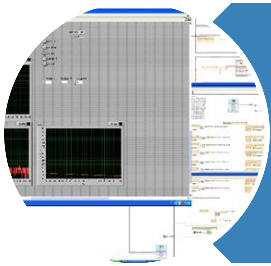


Renewable Energy Source

Energy Storage

Non Renewable Energy Source

Content of the work



Laboratory experimental tests

Adjustment of data gathered by instruments

Data Processing

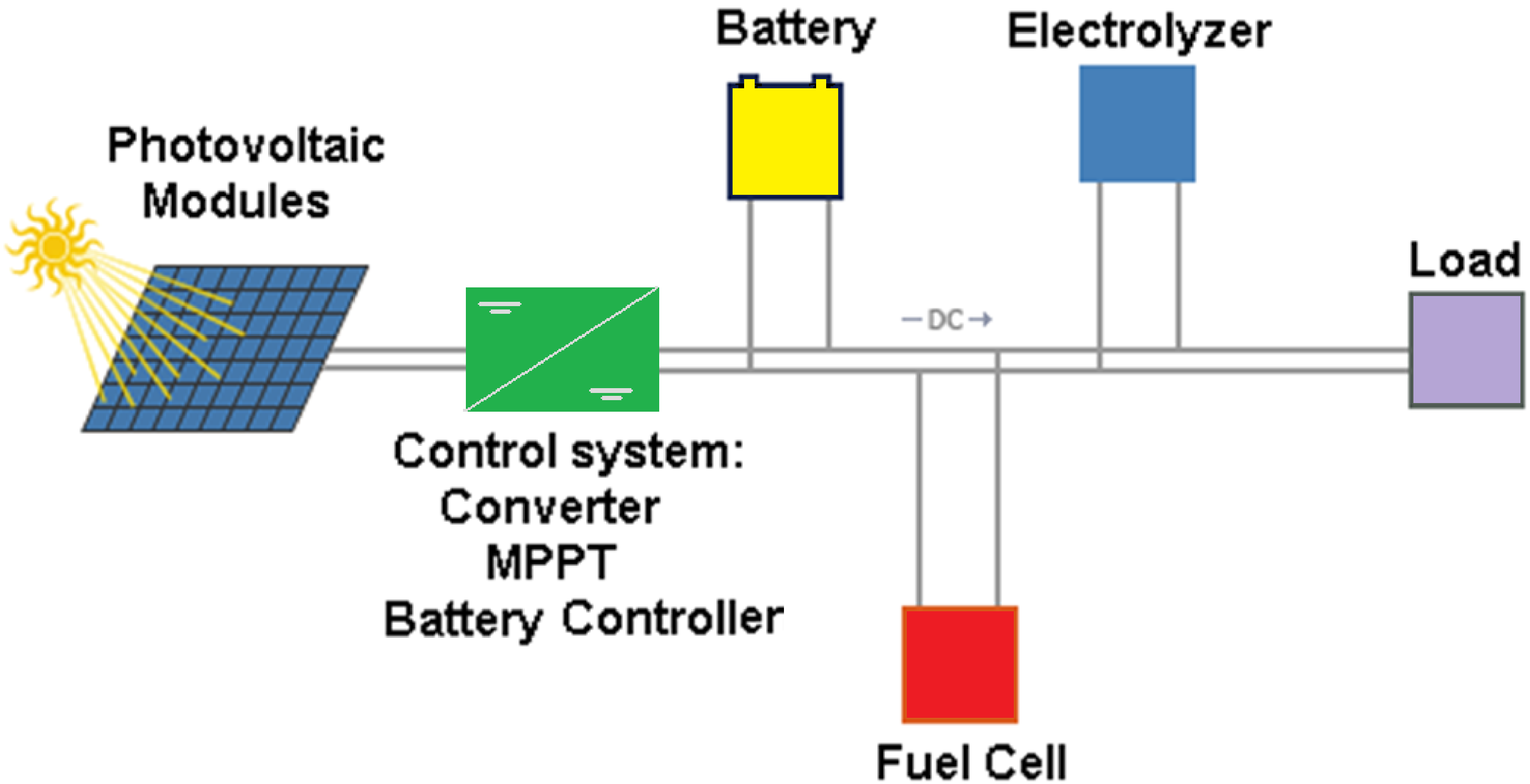
TARGET

➢ Evaluation of system performances (efficiencies)

INDEX

1. *Description of the hybrid system*
2. *Control strategy*
3. *Experimental tests*
4. *Instruments calibration*
5. *Operations: data acquisition,correction,calculation of performances*
6. *Test results*
7. *Conclusion*

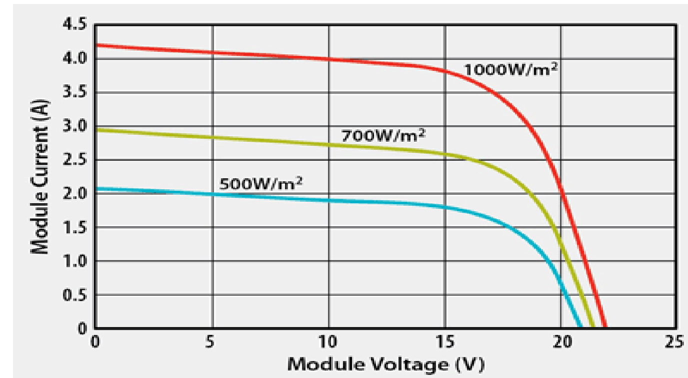
The hybrid system



- *All components connected in parallel on a DC bus.*
- *Load continuously powered.*

Photovoltaic Panels

- ➢ Energy from sun: highest priority of use
- ➢ MaximumPowerPointTracker and Charge controller



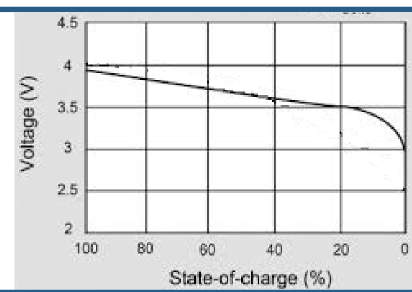
Batteries

- ➢ Lead-acid batteries

$$Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$$

$$PbO_2 + 4H^+ + 2e^- + SO_4^{2-} \rightarrow PbSO_4 + 2H_2O$$

- ➢ Depth of discharge

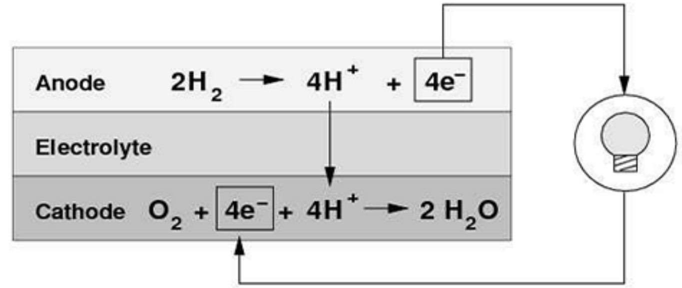


Fuel Cell

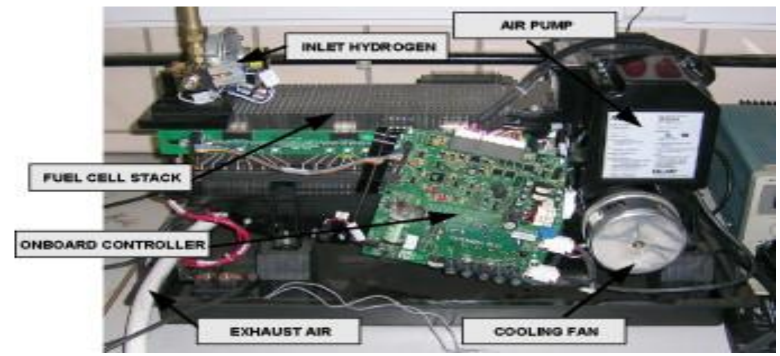
- ➥ Electricity from hydrogen electrochemical reaction
- ➥ PEMFC

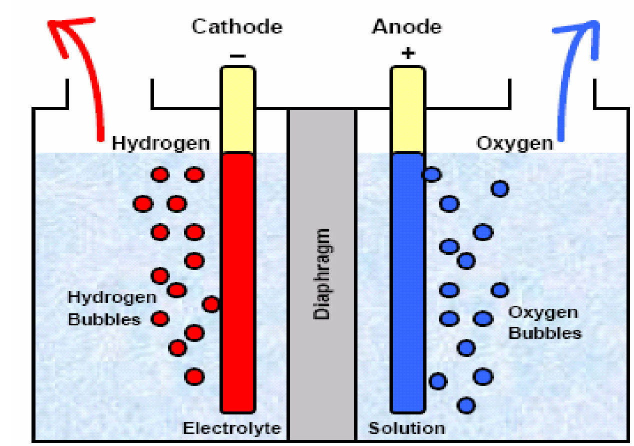
Electrolyzer

- ➢ Renewable energy seasonal storage
- ➢ Water electrolysis



Dan Hamilton, 2005





Standard Electrolysis

1. *Description of the hybrid system*
2. *Control strategy*
3. *Experimental tests*
4. *Instruments calibration*
5. *Operations: data acquisition,correction,calculation of performances*
6. *Test results*
7. *Conclusion*

Control strategy

↻ Load power as reference quantity

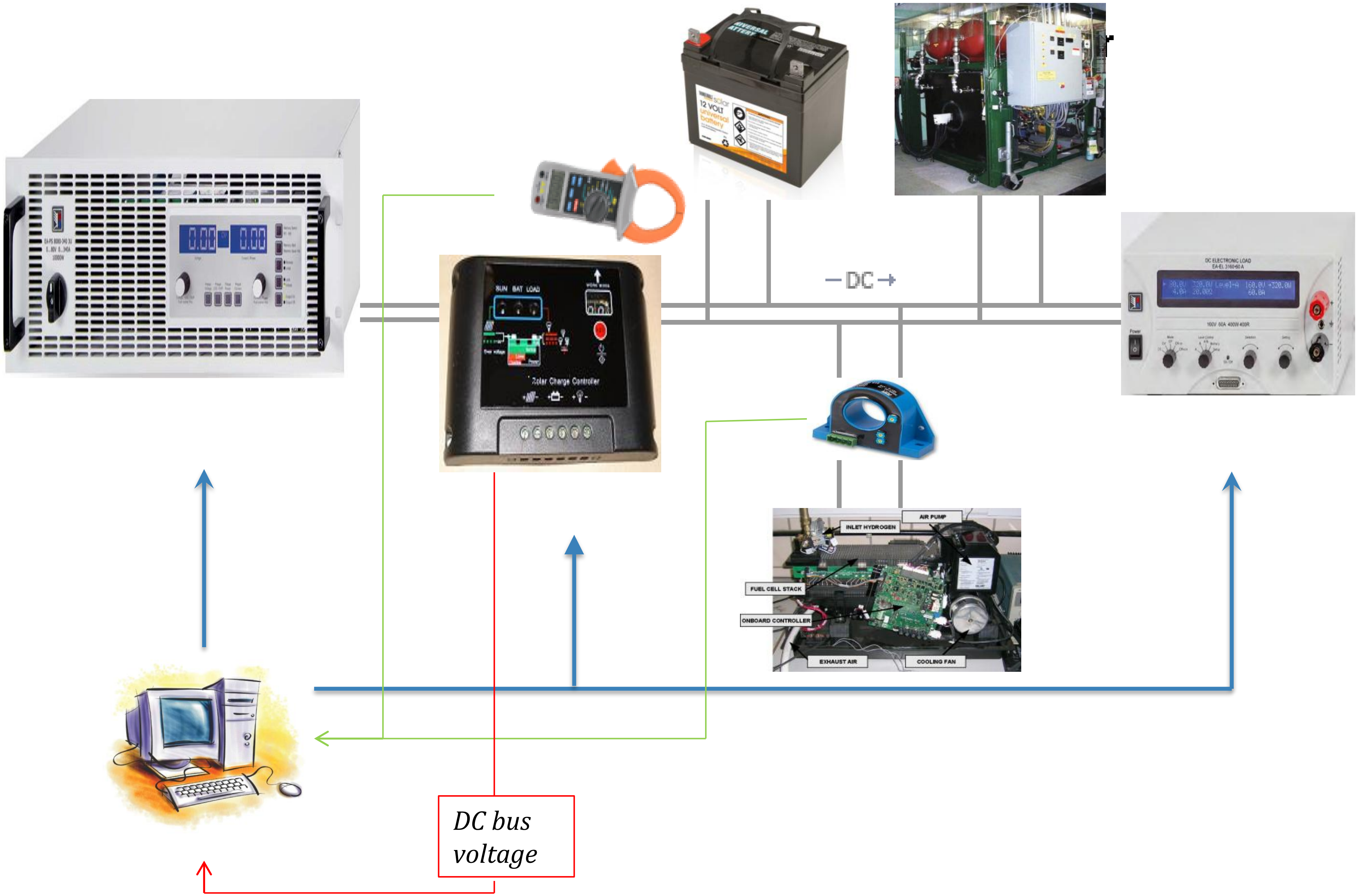
- *PV Power > Load Power* → Battery recharges (Bus voltage increases), Electrolyzer ON (if battery fully charged)

- *PV Power < Load Power* → Battery discharges (Bus voltage decreases)

- *PV power + Battery Power < Load Power* → Fuel Cell starts operating (constant voltage on the bus)

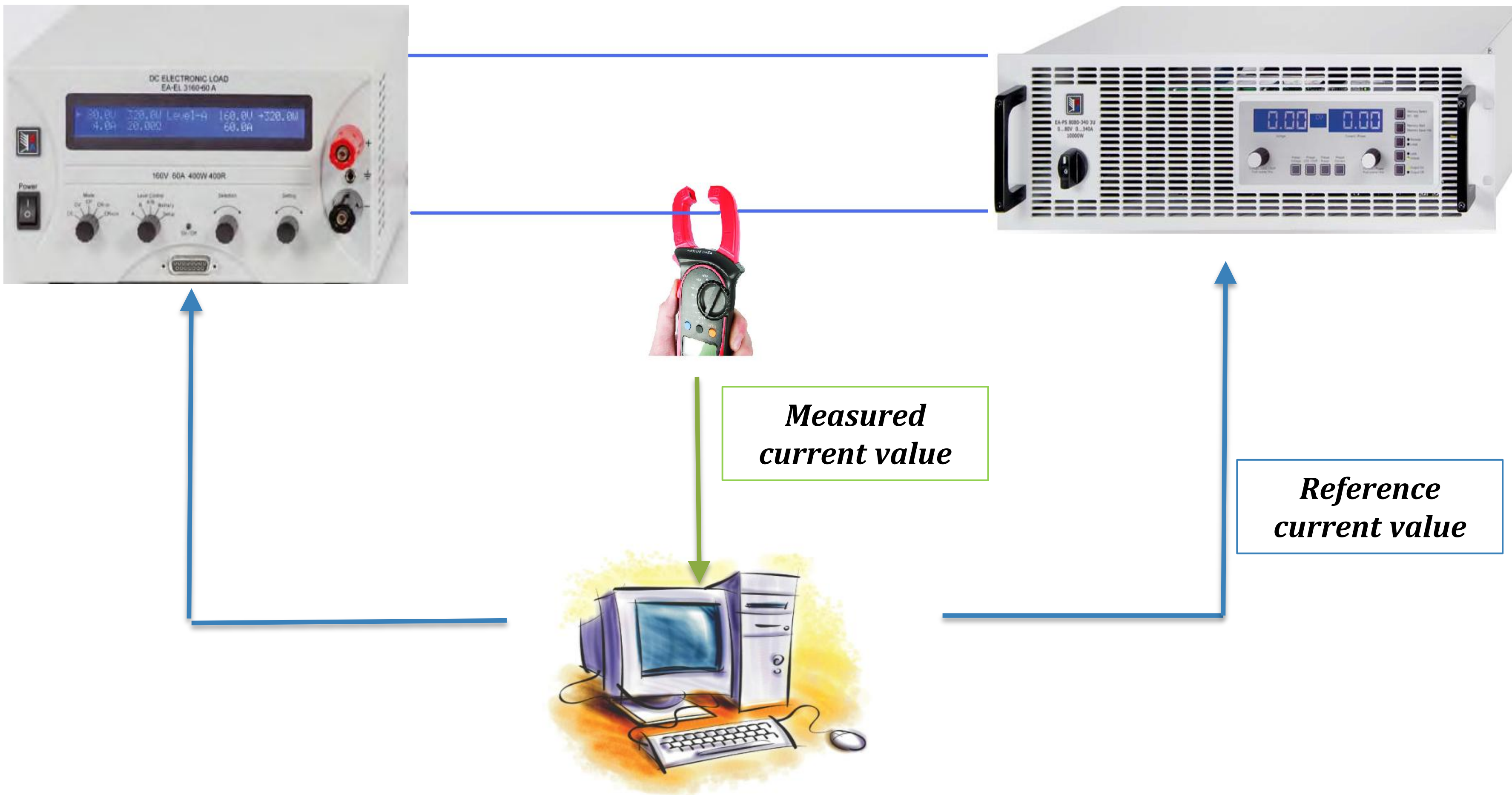
1. *Description of the hybrid system*
2. *Control strategy*
3. *Experimental tests*
4. *Instruments calibration*
5. *Operations: data acquisition,correction,calculation of performances*
6. *Test results*
7. *Conclusion*

Experimental setup



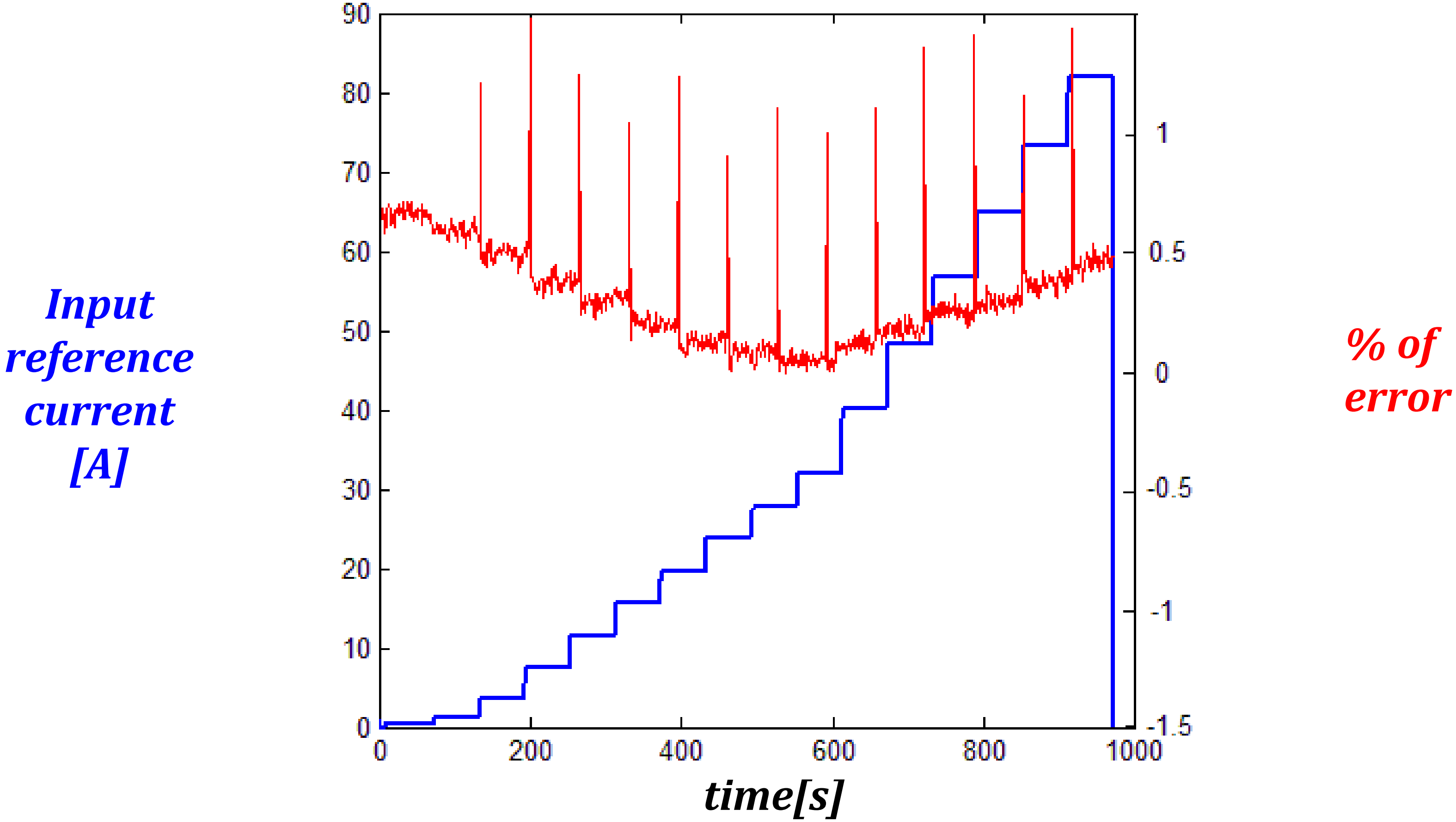
1. *Description of the hybrid system*
2. *Control strategy*
3. *Experimental tests*
4. ***Instruments calibration***
5. *Operations: data acquisition,correction,calculation of performances*
6. *Test results*
7. *Conclusion*

Instruments characterization: experimental setup



Instrument systematic error* = *Measured current value* – *Reference current value

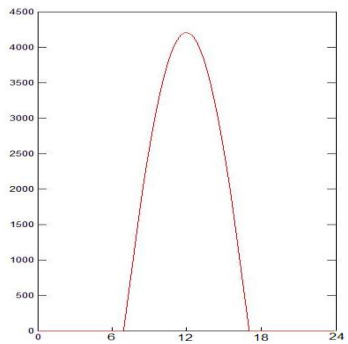
Trend of the instrument error and reference current with respect to time



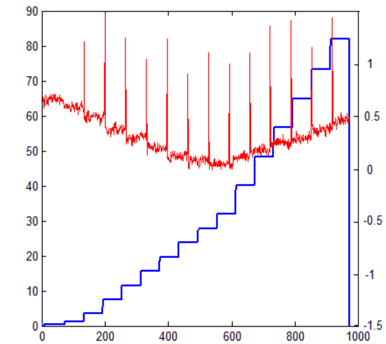
✓ For each measuring instrument, the error showed was in the tolerance range indicated by its producer!

1. *Description of the hybrid system*
2. *Control strategy*
3. *Experimental tests*
4. *Instruments calibration*
5. *Operations: data acquisition,correction,calculation of performances*
6. *Test results*
7. *Conclusion*

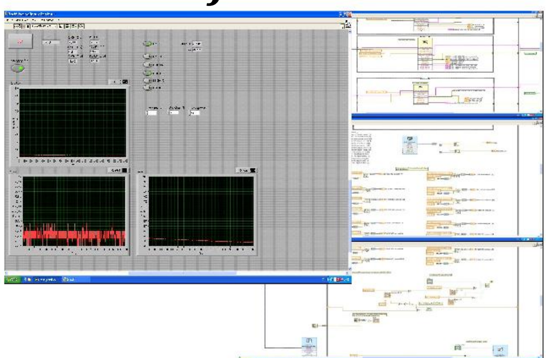
24h test



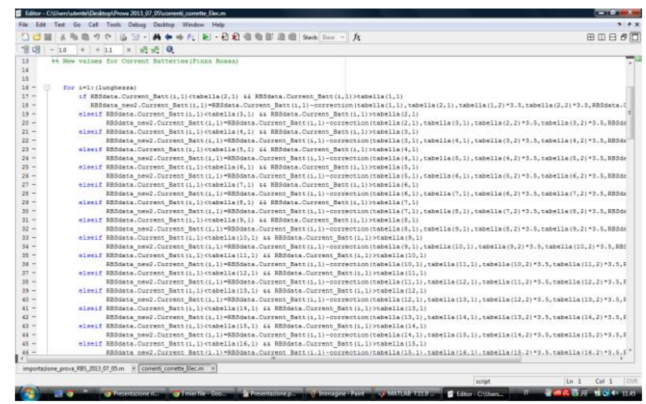
Getting error data



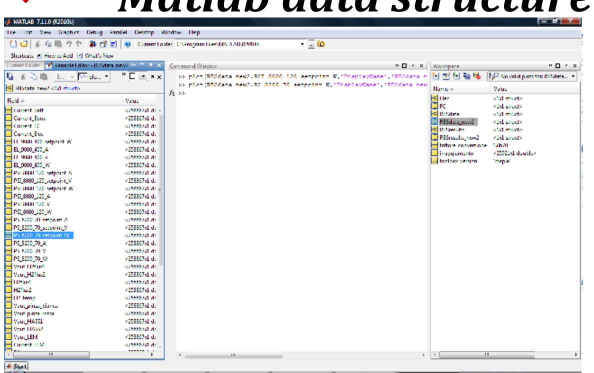
LabView file



Matlab code for data processing



Matlab data structure



Applied to...

DATA READY FOR ANALYSIS

Performance indicators

- ➢ *Energy released/acquired by each component*

$$E_{out} = \int_0^t V_{bus}(t)\, I_{comp}(t)\, dt$$

- ➢ *From energy to efficiency of overall system and its parts*

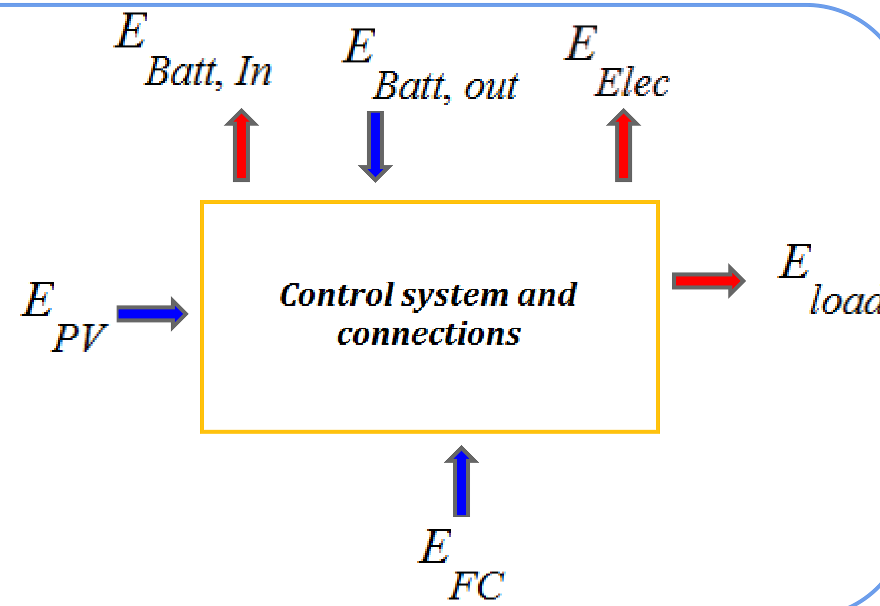
$$\eta_{subsystem} = \frac{E_{out}}{E_{in}}$$

- ➢ *Hydrogen consumption/production*

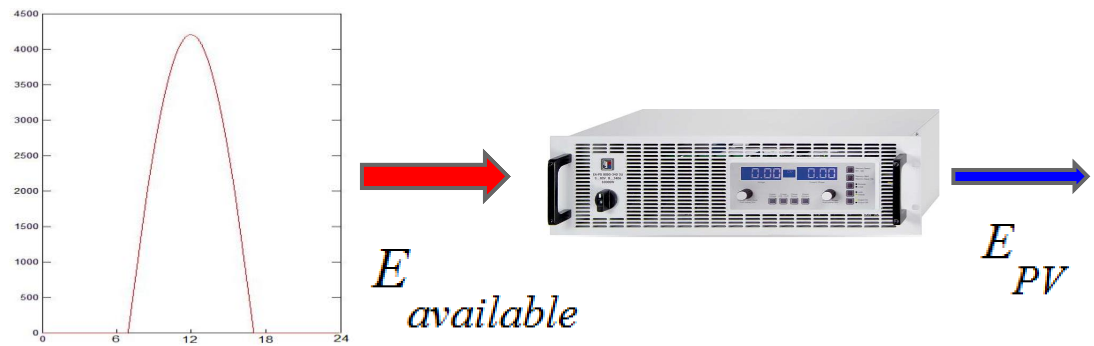
$$m_{H_2} = \int_0^t \mathring{m}(t)\, dt$$

Focusing on efficiencies…

$$\eta_{sys} = \frac{E_{load} + E_{Elec} + E_{Battery,\,In}}{E_{PV} + E_{FC} + E_{Battery,\,Out}}$$



$$\eta_{util,\,sun} = \frac{E_{PV}}{E_{Available}}$$

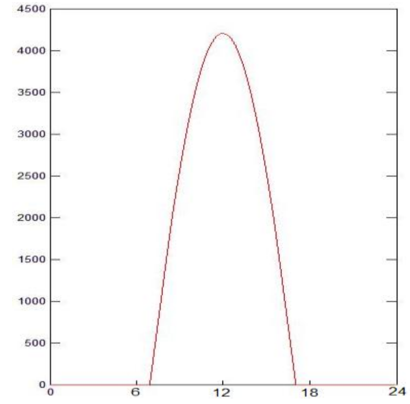


$$\text{"\%"}_{EnergyFromRenewables} = \frac{E_{PV}}{E_{load}}$$

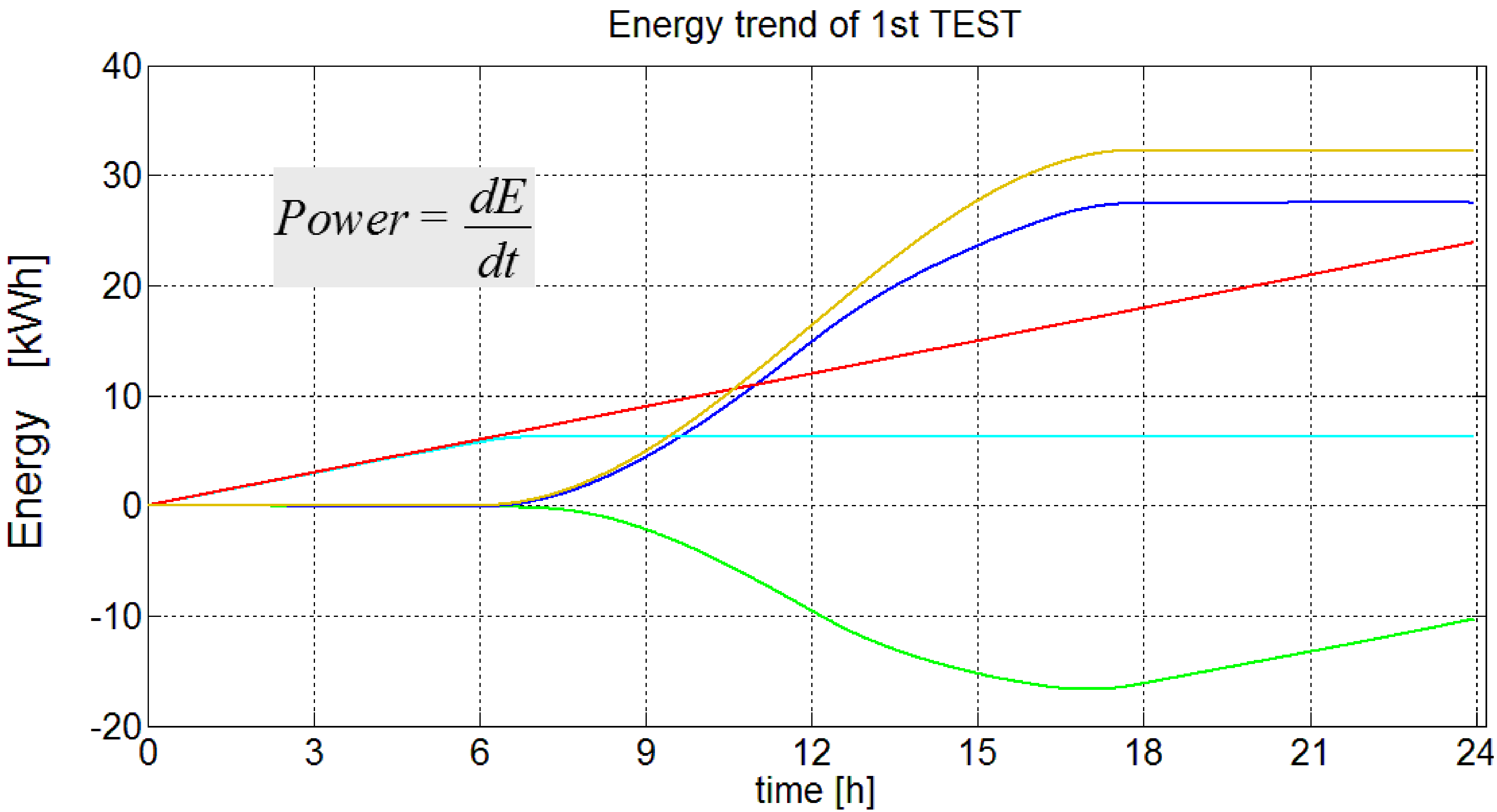
1. *Description of the hybrid system*
2. *Control strategy*
3. *Experimental tests*
4. *Instruments calibration*
5. *Operations: data acquisition,correction,calculation of performances*
6. *Test results*
7. *Conclusion*

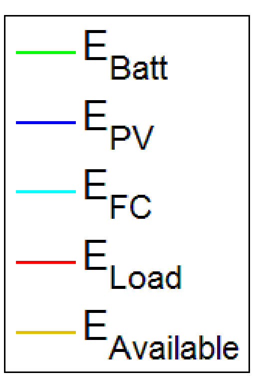
1st TEST:

- ✓ *24 h test*
- ✓ *Simulation of a sunny day irradiance profile*
- ✓ *No electrolyzer*



η_{sys}	*0.941*
$\eta_{Util,\ sun}$	*0.93*
$\%_{EnergyFromSun}$	*126%*
η_{FC}	*0.453*
m_{H2}	*0.418 Kg*





$$Energy\ unbalance = E_{PV} + E_{FC} + E_{Batt,\ OUT} - E_{load} - E_{Batt,\ IN}$$

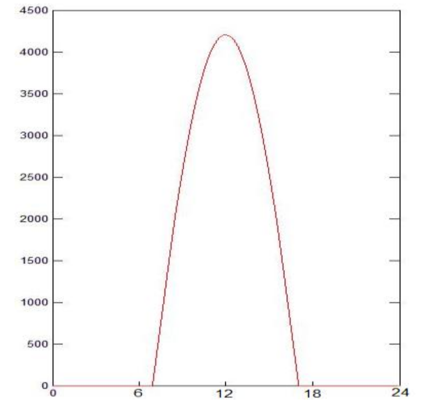
$$= \pm 1{,}7\ kWh\ (\ out\ of\ 33{,}3\ kWh\ entering)$$

$$Charge\ unbalance = C_{PV} + C_{FC} + C_{Batt,\ OUT} - C_{load} - C_{Batt,\ IN}$$

$$= \pm 33\ Ah\ \ (\ out\ of\ \ 654\ Ah\ entering)$$

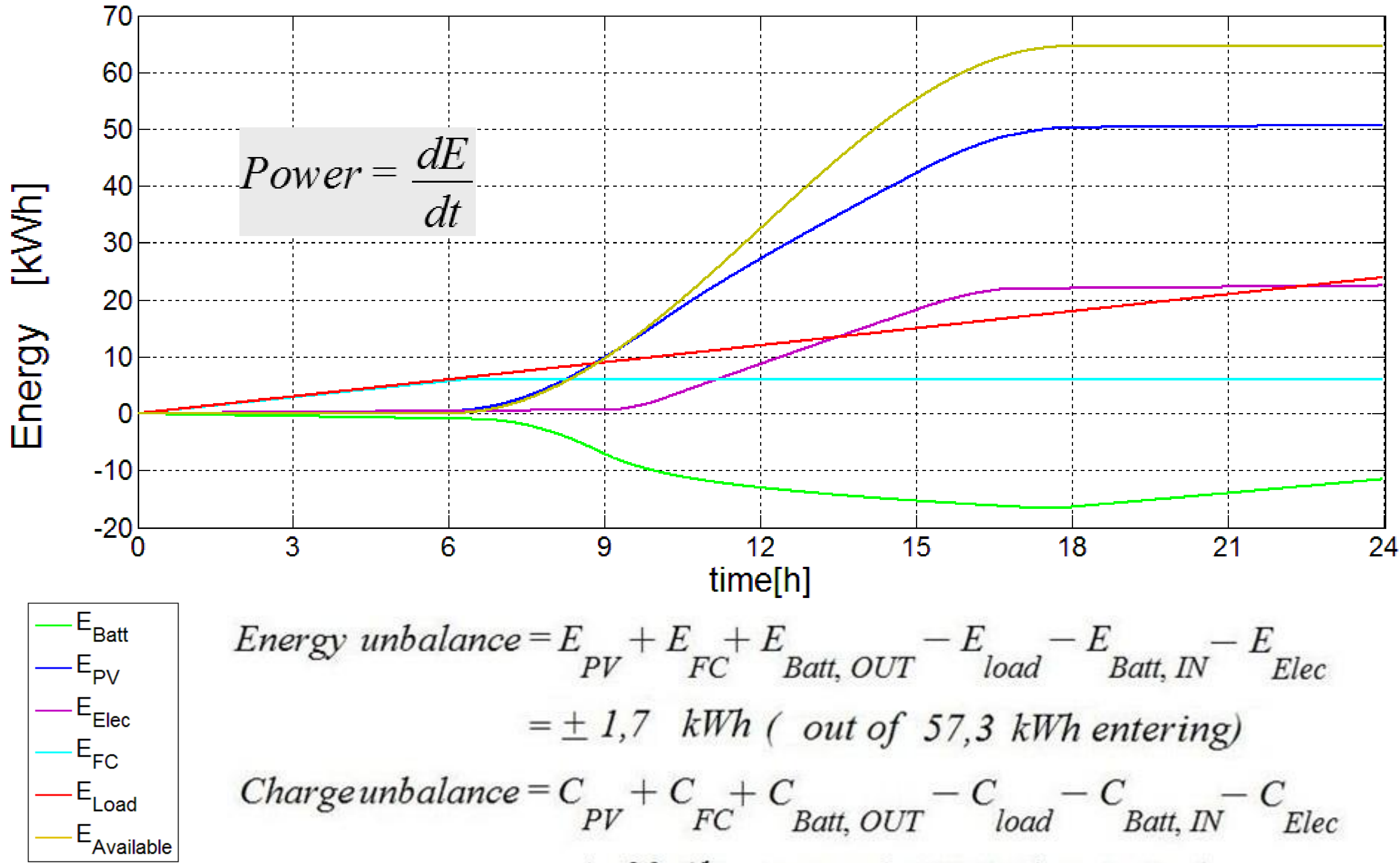
2nd TEST:

- ✓ *24 h test*
- ✓ *Simulation of a sunny day irradiance profile*
- ✓ *Electrolyzer*
- ✓ *PV power doubled*



η_{sys}	0.955
$\eta_{Util, sun}$	0.803
$\%_{EnergyFromSun}$	216%
η_{FC}	0.435
m_{H2}	0.416 Kg
η_{Elec}	0.478
$m_{H2, prod}$	0.323 Kg

Energy trend of 2nd TEST



$$Energy\ unbalance = E_{PV} + E_{FC} + E_{Batt,\ OUT} - E_{load} - E_{Batt,\ IN} - E_{Elec}$$

$$= \pm\ 1{,}7\ \ kWh\ (\ out\ of\ \ 57{,}3\ \ kWh\ entering)$$

$$Charge\ unbalance = C_{PV} + C_{FC} + C_{Batt,\ OUT} - C_{load} - C_{Batt,\ IN} - C_{Elec}$$

$$= \pm\ 33\ Ah\ \ (\ out\ of\ \ 1074\ Ah\ entering)$$

1. *Description of the hybrid system*
2. *Control strategy*
3. *Experimental tests*
4. *Instruments calibration*
5. *Operations: data acquisition,correction,calculation of performances*
6. *Test results*
7. *Conclusion*

Conclusions

The presented calibration of current clamps has been successful as:

- ✓ *It allowed for accurate measurements of individual component and overall system performances.*
- ✓ *Energy and charge balance have been closed with an accuracy within 5% for the first test and 3% for the second test.*

Moreover

- ✓ *The analysis of system behaviour under a sunny day shows good performance parameters of the individual components (e.g. FC and Electrolyzer efficiencies), giving a high interest toward its realization .*

THANKS FOR YOUR ATTENTION!