Electric Energy Storage Systems & Applications

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https://academics.georgiasouthern.edu/international/international-initiatives/erasmus/
Outline:

- Basic - Energy and Energy Storage Systems (ESS)
- Batteries (BAT) & Supercapacitors (SC)
- Electric Storage Cells - Parameters
- Batteries & Supercapacitors Technologies
- Hybrid Electric Storage Systems (HESS)
- ESS/HESS Stationary Applications
- ESS/HESS Mobile Applications
- ESS/HESS Application for Sensing Devices
- Future Developments
- Conclusions
Basic aspects

- **Energy**: Ability to provide an action or mechanical work
- The *multidimensional character of* energy forms: electrical, mechanical, chemical, thermal, radiant, etc.
- Electrical energy must be consumed when it is produced (*volatility*), in all other situations losses occur
- **Finite character** of energetic resources and power generation
- Offer an *Integral image* of movement as reflection of energy
- **Storage** ability to keep energy an undetermined period of time
Electrodes represent parts of storage devices connected directly or indirectly to the cell’s external circuit. These form together with the electrolyte the **anode and cathode** interfaces:

- **anode** - oxidation reactions, generating electrons on the battery’s external circuit.
- **cathode** - reduction reactions that capture the electrons from external battery’s circuit.

In case of batteries (non faradaic phenomena) all these exchange of charge are based on chemical reactions and illustrate in fact, the Gibbs energy of successive interfaces occurring inside battery among his electrodes including the electrolyte molecules.
Batteries (BAT) & Supercapacitors (SC) components
Basic aspects related Electric Energy Storage: Faradaic Phenomena

- Chemical energy is converted to electrical energy through oxidation and reduction reactions.
- Material gives up electrons: oxidation occurs at anode.
- Material takes in electrons: reduction occurs at cathode.
- Salt bridge(electrolyte): allows ions to move between cells (anode & cathode).
- Example:
  - Anode: \( \text{Zn} \rightarrow \text{Zn}^{+2} + 2 \text{e}^- \)
  - Cathode: \( \text{Cu}^{+2} + 2\text{e}^- \rightarrow \text{Cu} \)
Examples of electrochemical systems (Batteries)

Oxidizer | Electrolyte | Reducer

PbO$_2$ | 30-40% H$_2$SO$_4$ | Pb

Lead – Acid Battery

$\text{PbO}_2 + 3\text{H}^+ + \text{HSO}_4^- + 2e^- \rightleftharpoons \text{PbSO}_4 + 2\text{H}_2\text{O}$

Ch Dis

$\text{Pb} + \text{HSO}_4^- \rightleftharpoons \text{PbSO}_4 + \text{H}^+ + 2e^-$

Ch Dis

$\text{PbO}_2 + \text{Pb} + 2\text{HSO}_4^- \rightleftharpoons 2\text{PbSO}_4 + 2\text{H}_2\text{O}$

Dis Ch

Lithium Ion Batteries

$\text{Li}_y\text{Ni}_x\text{O}_2 + x\text{Li}^+ + x\text{e}^- \rightleftharpoons \text{Li}_y x\text{Ni}_x\text{O}_2$

Dis Ch

$\text{Li}_y\text{Ni}_x\text{O}_2 \rightleftharpoons \text{Li}_y\text{Co}_x\text{O}_2$

$\text{Li}_y\text{Ni}_x\text{O}_2 \rightleftharpoons \text{Li}_y\text{Mn}_2\text{O}_4$
Batteries

Lithium Ion Batteries

- Convert chemical energy in electrical energy and vice-versa
- Presents an aging process
- Need control of the State of Charge
- Temperature play an essential role, so must be strictly controlled
- Uniformity of the reactant phases is essential to diminish the aging effects
- Time variation of instantaneously signals influence the stability and reliability of batteries too

Source: [http://cpb.iphy.ac.cn/article/2016/1806/cpb_25_1_018210.html](http://cpb.iphy.ac.cn/article/2016/1806/cpb_25_1_018210.html)
• The electrode spatial distribution of matter determines the capacity and also the current density in correlation with the charge carriers from the electrolyte

• This is happening at the anode and the cathode too
Basic aspects related Electric Energy Storage: Non Faradaic Phenomena

Planar condensator

Capacity: 
\[ C = \varepsilon_0 \varepsilon_r \frac{A}{d} \]

Power: 
\[ P = \frac{V^2}{4 \cdot R_{ESR}} \]

Energy: 
\[ W = \int_0^Q V \, dq = \int_0^Q \frac{q \, dq}{C} = \frac{1}{2} \cdot \frac{Q^2}{V} = \frac{1}{2} C \cdot V^2 \]
Supercapacitors

Classification of super-capacitors:

- Electrostatic
- Electrical Double Layer Capacitors (EDLC)
- Pseudo capacitor
- Lithium Ion capacitor

Source: https://www.youtube.com/watch?v=FjZKm5khaAA

Source: https://pubs.rsc.org/en/content/getauthorversionpdf/C5CS00303B

Na+ (cyan), Cl- (purple).

1M NaCl

2ns with frames separated by 2ps
Cells, Devices, Systems

- Topologies
- Balancing
- Packaging

Sources:
- www.invenox.de
- http://pubs.rsc.org/en/content/articlelanding/2014/ee/c4ee01432d#divAbstract

Applications:
- Lead Acid 2.2V
- NiMH 1.2V
- Li-Ion 3.6V
- LiFePO₄ 3.0V

Level of Integration

System
Device
Cells
Electric storage cells parameters
Energetic parameters

- **Energy density**

- **Power Density**

Source: [https://www.nature.com/articles/nenergy201630/figures/6](https://www.nature.com/articles/nenergy201630/figures/6)

Electric Storage Cells - Parameters (1/2)

- Capacity of battery represents the amount of energy able to be provided by a battery during a complete discharging process. (measured in Ampere-hours)

- \( C_{rate} \) of a battery is a proportion of battery’s capacity. (e.g. 100Ah represents the amount of charge equal with the the capacity of battery to provide during 1 hour 100A at the same voltage. 1C of a 100Ah battery, represents 100A provided by battery)
Total amount of energy stored by device

\[ W_c = \frac{1}{2} C \cdot V^2 \]

where C is electrostatic capacity measured in Farads, and the V represents the V (voltage) measured between the capacitor’s plates.

- Power provided by a supercapacitor:

\[ P = \frac{V^2}{4 \cdot R_{ESR}} \]

\( R_{ESR} \) represents equivalent series resistance.

Capacity of supercapacitor is the result of geometrical design of the capacitor cell dimensions: \( C = \varepsilon \frac{s}{d'} \).
Electric Energy Storage: Faradaic Phenomena

• The percentage of the maximum possible charge that is present inside a rechargeable battery:

\[
\text{SoC} = \frac{C_{\text{releasable}}}{C_{\text{rated}}} \cdot 100\%
\]

• State of Health represents a measurement that reflects a battery’s general condition and its ability to deliver the specified performance in comparison with a fresh Battery.

\[
\text{SoH} = \frac{C_{\text{max}}}{C_{\text{rated}}} \cdot 100\%
\]

• Depth of Discharge:

\[
\text{DoD} = \frac{C_{\text{released}}}{C_{\text{rated}}} \cdot 100\% \quad \text{or} \quad \text{DoD} = 100\% - \text{SoC}
\]
**Batteries & Supercapacitors: Electrodes**

**Flexible all-solid-state supercapacitor using paper like PANI coated CNT**

Specific capacitance $350 \text{F g}^{-1}$

---

**Equivalent circuit model for an electrochemical capacitor**

\[
\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}
\]

---

Are substances with a high molecular polarity which promote dissociation of dissolved electrolytes

*Water polarity* \( \varepsilon = 78.5 \)

Non aqueous solvents can be classified as:
- **Protic** analogous to water
- **Aprotic** polar when \( \varepsilon > 15 \)
- **Aprotic with zero polarity** when \( \varepsilon < 15 \)

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Formula</th>
<th>( \varepsilon )</th>
<th>( \eta )</th>
<th>( d )</th>
<th>( t_f )</th>
<th>( t_b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>H(_2)O</td>
<td>78.5</td>
<td>0.89</td>
<td>0.997</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>CH(_3)COOH</td>
<td>6.2</td>
<td>1.13</td>
<td>1.05</td>
<td>16.7</td>
<td>-118.1</td>
</tr>
<tr>
<td>Acetonitril</td>
<td>CH(_3)CN</td>
<td>36</td>
<td>0.345</td>
<td>0.786</td>
<td>-45.7</td>
<td>81.6</td>
</tr>
<tr>
<td>Polypropylene carbonat</td>
<td>CH(_3)CO-O</td>
<td>CH(_3)-C=O</td>
<td>66.1</td>
<td>2.53</td>
<td>1.198</td>
<td>-49.2</td>
</tr>
</tbody>
</table>

\( \eta \) viscosity \([Mpa \cdot s]\)  
\( d \) density \([g/cm^3]\)  
\( t_f \) freezing – point °C  
\( t_b \) boiling – point °C
Batteries & Supercapacitors
components: Electrolytes for SC

- Aqueous
- Organic
- Ionic liquids, solid-state or quasi-solid-state
- Redox-active electrolytes

Advantages and Disadvantages of SC

Advantages:
• Very Short Time Constant
• Large Temperature Domain -40°C to +70°C
• Very high life span (1,000,000 cycles)
• Very high energy efficiency 98% in case of bidirectional exchange of power
• Can be completely discharged - not harmful
• High Power Density

Disadvantages:
• Lack of plateau during discharging
• Self Discharge
• Low Energy Density
## Batteries vs. Supercapacitors

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Supercapacitors</th>
<th>Battery Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy density</strong></td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>10-20wh/kg, peak value 26.7wh/kg</td>
<td>80-300 wh/kg dependent on technology peak value Li-O₂ 3500wh/kg</td>
</tr>
<tr>
<td><strong>Power density</strong></td>
<td>High to Very high</td>
<td>Moderate to High</td>
</tr>
<tr>
<td></td>
<td>1 - 5 kW/kg, peak value above 20kW/kg</td>
<td>0.25 – 1.3 Kw/kg dependent on technology (see Error! Reference source not found.)</td>
</tr>
<tr>
<td><strong>Domain of temperature</strong></td>
<td>Extended</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>-50°C to +60°C</td>
<td>0°C to 45°…… 50°C (dependent on technology)</td>
</tr>
<tr>
<td><strong>Cyclability</strong></td>
<td>Very high</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>500,000 cycles to 1,000,000cycles</td>
<td>200 to 5,000 full cycles (DoD 95%)</td>
</tr>
<tr>
<td><strong>Voltage</strong></td>
<td>1 - 2.7V</td>
<td>1.2 - 4.5V</td>
</tr>
<tr>
<td></td>
<td>Inorganic electrolyte 1-1.2V</td>
<td>Lead-acid 1.2V</td>
</tr>
<tr>
<td></td>
<td>Organic electrolyte 2,7 - 3V</td>
<td>Li-Ion 3.7V</td>
</tr>
<tr>
<td></td>
<td>Asymmetric electrodes 4,5V</td>
<td>LiFePO4 3V</td>
</tr>
<tr>
<td><strong>Self-discharge</strong></td>
<td>Very low</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Energy efficiency</strong></td>
<td>92 to 98%</td>
<td>85 to 92%</td>
</tr>
</tbody>
</table>
Hybrid Electric Storage Systems (HESS) (Biological Systems Analogy)
Human Muscle Cells vs. ESS/HESS

Time constants corresponding to the main energetic resources in living organisms
Hybrid Electric Storage Systems
(analogy with biological systems)

- **Time constants of our body’s energetic reserves:**
  - Energetic reserves of the living cells:
    - **ATP** acid adenosine triphosphate (short term energy, locally stored)
    - **ADP** acid adenosine di-phosphate (intermediate term energy, locally stored)
    - Glycogen carried by blood from liver to all the body’s cells
  - Density / Energetic capacity
    - **ATP** stored in principal into the cell – generate a 7.3Kcal / link molecule oxidation
      - $\text{ATP} + \text{H}_2\text{O} \rightarrow \text{ADP} + \text{Phosphate} - \Delta7.3\text{Kcal/mol}$
    - **ADP** also stored into the cell and could be used as energetic reservoir
      - $\text{ATP} + \text{H}_2\text{O} \rightarrow \text{AMP} + \text{PP}_i - \Delta10.9\text{Kcal/mol}$
    - Glycogen depending of the quantity that is stored into the liver
Is a cell an ideal storage system?

A bio-cells group represents a distributed energetic system.

The group of cells represents a redundant energetic and also informational source (a compensation phenomena can be identified in organism).

A bio-cell has the ability to auto insulate from the whole system, without global damages.

A bio-cell assures a “flat time response” for energy & power delivered on demands (very short, short and long term).

Able to auto-reconfigure depending of status of process supplied.
Energetic resources in living organisms

• Involves distributed “reserves” stored into different body’s cells
• Includes two categories of “reserves”: for short & medium term needs
• Allow fast reaction of the cells at different excitations
• Allow a “flat response” for the whole system
• The local energetic “reserves” are finite
• “Transportation” processes of the energetic resources, activated to satisfy the energetic needs for medium and long term
• A appropriate sizing of every element in order to assures the right balanced ratio between long & short term energetic resources

• An adequate dimensioning of hybrid system in order to satisfy the needs of bidirectional power flow transfer –requested by the specific application

• A “flat response” in time of the hybrid cell
Hybrid Electric Storage Systems
(Paradigms provided by biologic Systems)

LIVING SYSTEMS:
- The assembly of cells having **similar functionality** for a living tissue
- **Integration** of cells means to obtain new features as result of the internal interactions between the cells. Thus, the assembly (organ) will present qualitative/quantitative different feature compared with the sum of component cells
- A **high reliability** is reached as result of highly structurally and functionally redundancy

TECHNICAL SYSTEMS:
- Need to be **closely interconnected** each to other. The **preemptive** wiring solutions are in many cases the optimal from energetic efficiency point of view
- It is mandatory to include on every cell a **minimal set of functions**. Implementation in this case suppose usage of **microcontroller** or **ASIC** circuits. That illustrate the fusion Energy & Information
- Behavioral or/and Self Dynamic reconfiguration is an important feature of such systems
Hybrid Electric Storage Systems
(Paradigms from biological systems)

- **Hierarchy and Complementarity**
  - **Order relationships** are fundamental to achieve the optimization of **information flows**
  - In the same sense goal is essential to realize a **proper classification**
  - Locally implements a **static or /and dynamic** grouping of the cells in colonies depending on their role and applications specific

- **Functional feature**
  - **Complementarity** (structural & functional) of electric hybrid storage system contributes at **optimal** and **reliable** implementation of bidirectional power flow transfer with beneficial consequences for increasing of global energy efficiency
ESS/HESS Stationary Applications
Smart Grids

Definitions:

- **Smart Grids (EU):** Power network that efficiently integrates the behavior and the actions of all users interconnected — generators, consumers (loads), different participants into the grid in order to offer sustainable and reliable functioning.

- **Smart Grid Strategic Group (IEC):** A concept for modernization of power networks that integrate the energy and information technologies in any point of the network from generation to consumption.

```
- Intelligent:
  □ Metering (Advanced Metering Infrastructure),
  □ Controlling (SCADA, prevention of outages, self healing, optimization of power excursion, usage of smart storage systems, frequency monitoring)
  □ Scheduling of power generation & consumption – profiling and acting in accordance with determined demand profile
  □ Transmission of power
  □ Distribution of power

- Automatic reaction in case of exceptions that appear in functioning of the power network
- Awareness of consumer about energy consumption consequences
- Transforming of consumer in prosumer (producers & consumers of energy)
```

A generic definition means to offer for every body the synergic mean to be more efficient in the govern of complex networks

Fusion between:

Power network and information networks (Energy & Information)
• The storage devices are similar of cache memories inside computers

• If cache memories play the role of synchronization between different buses, the storage systems offer an extended time’ window facilitating the system services inside power networks
- Automatic smoothing and adaptation of RES generator at load demand and at the variate generation of RES function of solar radiation of wind speed
- Daily smoothing of power generation
- Avoid sags and peaks in generation
- Improve “quality of Energy” and harmonics in power.
Stationary Applications
Taxonomy of Energy

Prosumer Structure
Stationary ESS Facilities used for Grid Services

SWEMAG 5MW/5MWh offers services equivalent with 70MW classical power plant

- Primary frequency response
- Secondary frequency response
- Voltage support
- Islanding capability
- Black start capability
- Short-circuit power Oscillation damping
- Ramp rate control
- Renewables integration
- Gen-Set optimization
- Fuel reduction
- Grid investment deferral
- Peak Load management
- Self consumption optimization

Source: Yunicos Presentation ESE London 2015 „Let the fossils rest in peace“
Role of ESS/HESS in Mobile Applications:

• ESS/HESS provide or receive the energy necessary to “energize” the movement of vehicles
• Shortcut the energetic circuits by closing shortest possible energetic loop (generator-consumer)
• Improves significantly the energy efficiency of vehicles
• Improves dynamics of vehicles
• Dramatically reduces the pollution
Cells distribution into the car’s volume

- Weight reduction 15%
- Reduction of power flow excursion between batteries & acting motors
- Better balancing of the weight between axis of the car
POWER DISTRIBUTION ON A CAR TRANSITORY & STATIONARY POWER FLOWS

- Structured design with hierarchical elements
- Optimization by minimizing the power flows excursions between batteries & rapid release storage elements and the acting motors
- Better balancing of the weight between axis of the car
- Modular design
ESS/HESS Mobile Applications: Battery Technology for automotive

- **Class 1 (12V)**
  - Vehicles endowed with ICE
  - Start-Stop ICE vehicles
  - Micro-hybrid vehicles

- **Class 2 (48-400V)**
  - Advanced micro-hybrid vehicles
  - Mild Hybrid vehicles
  - Full Hybrid vehicles

- **Class 3 (250-600V)**
  - Plug In Hybrid Vehicles
  - Full Electric vehicle

See: A review of Batteries Technologies for Automotive Applications EUROBAT, AGM Starter battery, Johnson Controls

See: A review of Batteries Technologies for Automotive Applications EUROBAT, Li_Ion Batteries for EV Nissan
ESS/HESS Mobile Applications: Personal Electric Vehicles (PEV)

- Support services for integration inside smart cities
- Improved dynamic parameters like: speed, acceleration, allow a bigger biker weight, maximize the bicycle range, temperature domain 0-50°C

### Ecologic
- Use electrical energy
- Don’t produce wastes

### Efficient
- Minimize consumption
- Maximize parameters

### Friendly
- Don’t need license
- Public service

### Dynamics
- 15\(\leq\)25km/h
- 0\(\leq\)6 m/s²

### Range
- 16\(\leq\)80km;
- Life span >100000 cycles

### Consumption
- 150\(\leq\)1000w

Parameters:
- Maximum power: 1.5 kW
- Maximum speed more than 50km/h
- Life span: more than several 20,000 cycles
ESS/HESS Mobile Applications: Personal Electric Vehicles (PEV)

- Supervised by a Tablet PC that coordinate energy dispatch and also the optimization in real time of e-bike route.
- Maximum speed limited by electronics at 25km/h
- Autonomy more than 120km between two charging processes
- Recuperation of kinetic energy

Energization
- 60wh Li-Ion batteries; 58V; 20A
- 28F/32V super-capacitors with organic electrolyte

Dynamics
- High acceleration/deceleration
- Adapted to road slope conditions

Control Functions
- Driver throttle commands
- Routing optimization using google traffic info
- Forecasting features function of batteries SoC

e-bike prototype Block Diagram
ESS/HESS Mobile Applications: Examples: Locomotives, Trains

- Starting & Energy Management of a Diesel hydraulic heavy shunting locomotive:
  - Starting & Energy management System for a shunting locomotive

  - Main display panel of the starting system on locomotive
  - Engineer cabin of the locomotive
  - Hybrid storage cabinet
  - Supercapacitors pack 12F/110V Aqueous electrolyte

- Starting motor: 25Kw
- Switching devices:
  - SCR 1200V/1900A
  - IGBT 1200V/1200A
ESS/HESS Mobile Applications: Examples: Locomotives, Trains

- Hybrid Electric Storage Components
- Controlling system based on standard Laptop & an embedded system

Starting sequence:

- $K_0$: Start SC charging process
- $K_1$: Command Start ICE
- $K_2$: Switch SC to Battery
- Automatic stop starting process

Block Diagram

Starting process workflow
ESS/HESS Mobile Applications: Examples: Locomotives, Trains

- Instantaneous Parameters recorder during staring process of locomotive:

**Voltage Variation on Starting Motor**

**Current Variation on Starting Motor**

A voltage variation curve in time (Initial situation)
B voltage variation curve in time (on prototype)
C current variation curve in time (Initial situation)
D current variation curve in time (on prototype)
Features and advantages of implementation:

- More than 50% reduction of batteries capacity on board
- A reliable and energy efficient starting system for the Diesel engine locomotives
- The starting system increasing's the availability with 100% successful, even when the voltage on batteries was less than 90V
- The temperature range of devices is between -40ºC and +75ºC, maintaining a very low RESR (Equivalent Series Resistance) on the entire temperature range
- Extension of remaining batteries' lifespan by more than 200% with a lifespan of super-capacitors of about 10 years
- Reasonable reduction of both operational and capital costs due to reduced fuel consumption (mean daily savings for locomotive: 20 gallons l Diesel/day)
- CO₂ emissions / day with 148 Kg. Reduction of CO₂ emission 3.12 Kg CO₂/ Kg/day
ESS/HESS Mobile Applications: Examples:
Trains and Light Rail Vehicles (LEV)

• ESS Applied for energy optimization of the trains:
  Power Flow Excursion

• On board ESS dramatically reduce the power excursion during acceleration/deceleration of the train improving the dynamics and also the reliability of trains components (min 7-15%)

• For weak catenaries avoid under voltage periods

• ESS sink the regenerative breaking energy

• ESS provide for improving dynamics of vehicle the recuperated energy
• Saving of 30% of electrical energy by using ESS on board
• Improved aerodynamics generate a saving with 12% of energy consumed
• Engineer assistance improve the energy efficiency with 15%
• LVR management of energy reduce with 10% overall energy consumption
• Overall savings in exploitation of the LVR reach 20%

• LVR Energy /Power: 2 kWh / 600 kW
• A train with 30m length is endowed with two storage boxes

See: Cristian Koeber Eco 4 Bombardier Energy Saving Technologies And Their Applications, Bombardier Inc. 2008
ESS/HESS Mobile Applications: Examples:

Light Electric Vehicles (LEV)

- ESS on board improves overall energy efficiency, dynamics of vehicle, reliability and availability.
- ESS implementation on board has consequences on distribution and traction electrical grids by avoiding overcharging and under-voltages of catenary.

See: Steiner M, J Scholten, Improving Overall Energy Efficiency of Traction Vehicles
Intelligent/autonomous sensors

- Structure & Functionality of sensors:
  - Sensors;
  - Processors;
  - Energy sources
- Topology of the networks:
  - Mesh
  - Star
- Support for design and operating
- Operating systems - TinyOS
- Energetic autonomy

Mica 2 “smart dust” sensor

Infineon eyesIFX2.1 SDK
Sensor System Components

Bluetooth Low Energy v4.0, Wi-Fi or Zig-Bee

Wireless transceiver

Central Unit Processor

Features:
- Standardized
- Versatile
- Very low power

Serial interface

I²C Interface

AVR 8 bit processor

Digital Interface

Analogue Interface

Temperature & Humidity Sensor

Transducer

Non standard Sensor

Analog or Digital Interface
WSN’ Firmware and integration

Power on setup
- Initialize processor ports
- Initialize sensor & its interface
- Initialize transceiver

Integration into the network
- Settlement of sensor address
- Settlement of sensor parameters

Data Acquisition
- Wake-up
- Acquire data
- Memorize data acquired
- Power Management & wait

Firmware components
Wait data acquisition from server
Power on setup
Integration into the network
Data Acquisition
Applications: Autonomous Wireless Sensor Networks

Network controller

Sensors server

Network DAQ controlling

Data acquisition cycle controlled by the CPU timer

Wake-up
Wait
Acquire
Memorize
Data acquisition

Data transfer

Sleep

Sleep

Receive command

Transmit data

Pick-up data acquired

Wake-up

Pick-up data acquired

Receive command

Transmit data

Sleep

Wake-up
Effective, web-enabled thermal simulation system coupled with a cost-effective set of sensors (e.g. temperature, relative-humidity) that can provide valuable insights into

- building design,
- materials and construction
- significant energy savings
- an improved thermal comfort.

For more info please see:

http://projects.felixlup.net/thermal/index.html
Conclusions:

• Energy Storage Systems represents essential technological advances toward global optimization of all human activities

• The complexity of these systems require a multidisciplinary approach in research and development projects

• The condensed matter progress in correlation with the nanotechnologies evolutions create premises for tremendous extension of ESS/HESS applications

• Biotechnologies, Computer Science together with Intelligent Physical Systems will represent new domain where ESS/HSS will be applied in the near future.
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• For more information please see:

https://academics.georgiasouthern.edu/international/international-initiatives/erasmus/

and:

http://news.felixlup.net