BATTERIES LIFESPAN ESTIMATION IN A PHOTOVOLTAÏC SYSTEM WITH HYBRID STORAGE

A COMPARATIVE STUDY

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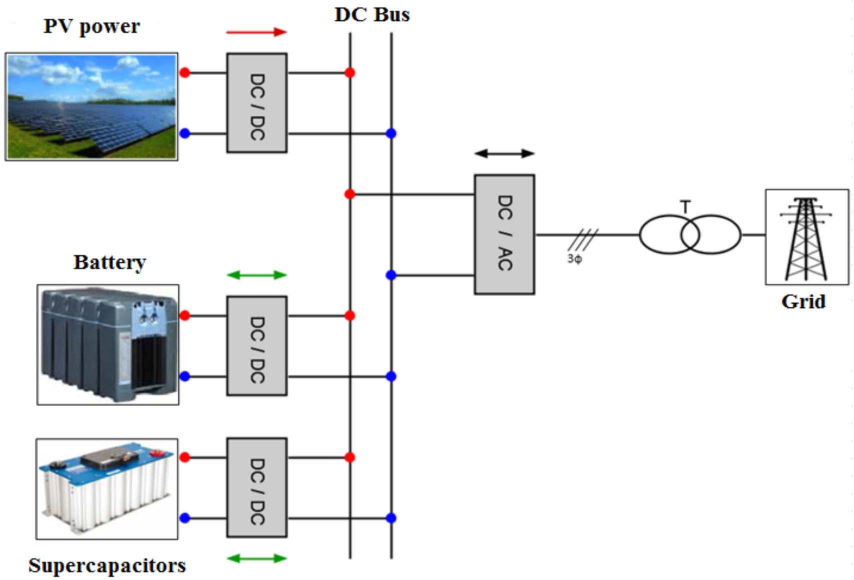

Plan

- INTRODUCTION
- STUDIED PHOTVOLTAIC SYSTEM DESCRIPTION
- SYSTEM ENERGY MANAGEMENT
- BATTERIES LIFESPAN ESTIMATION : PRINCIPLE OF BATTERIES DETERIORATION CALCULATING
- CASE STUDY AND SIMULATION RESULTS
- CONCLUSION AND PERSPECTIVES

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- The Energy productions from renewable energy sources such as photovoltaic generators are characterized by uncertainty and intermittence. They are greatly influenced by meteorological conditions.

- Thus, to ensure good stability of the electric network, it is necessary to store part of the produced energy. In fact, there are several methods of storage: potential form (STEP), kinetic (flywheel), hydrogen, in an electrochemical battery (lead, lithium) or a super-capacitor.

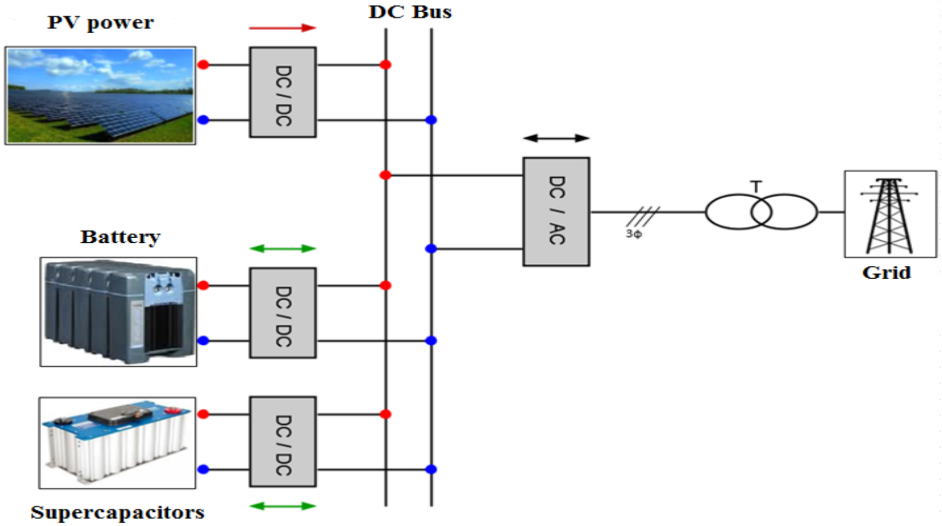
- Currently, there are several companies that sell storage solutions for network support or future integration into smart grids, such as:
  - ✓ Li-ion batteries containers (Saft, Mitsubishi Heavy Industries),
  - ✓ Batteries Sodium-Sulfur (NaS) (NGK),
  - ✓ Hydrogen production and storage systems (CETH2 and McPhy),
  - ✓ Flywheel systems (Vycon, Beacon Power),
  - ✓ Super-capacitors containers (Maxwell).

- However, It is rare at the moment a system dedicated to electricity network and combining these various technologies; these systems staying at the moment in development.

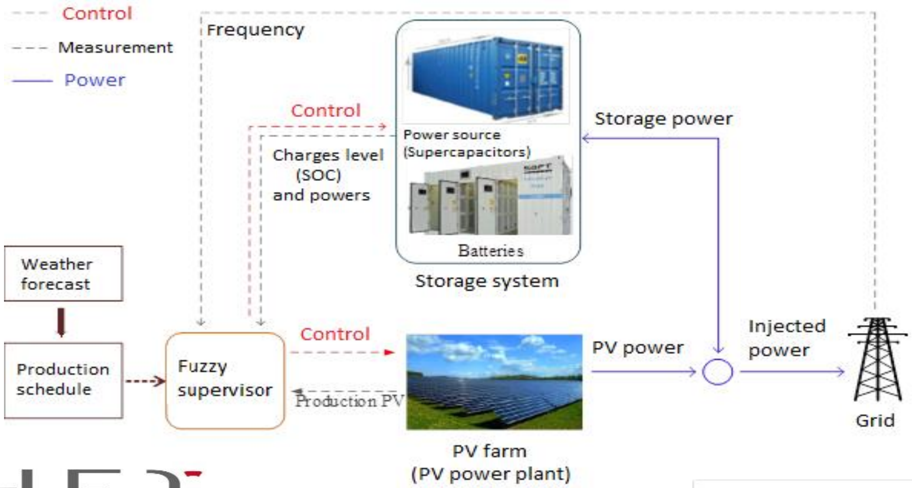
In this work, we have studied a photovoltaic system with hybrid storage. We focused on optimal system energy management using fuzzy logic and on batteries lifespan using rain-flow method for different storage combinations (batteries lithium NCA with Batteries NiMH or Li Fe PO4 or capacitors).

The main purpose of adding a source of power storage is to smooth the power flow in case of intermittency of photovoltaic source and to increase the lifetime of the energy storage one.

Architecture



Management structure



We consider a photovoltaic system with hybrid storage. Storage station is based on combination of two complementary technologies: a source of power storage (batteries NiMH or Li Fe PO4 or super-capacitors) and a source of energy storage (lithium batteries NCA with high specific energy).

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METHODOLOGY

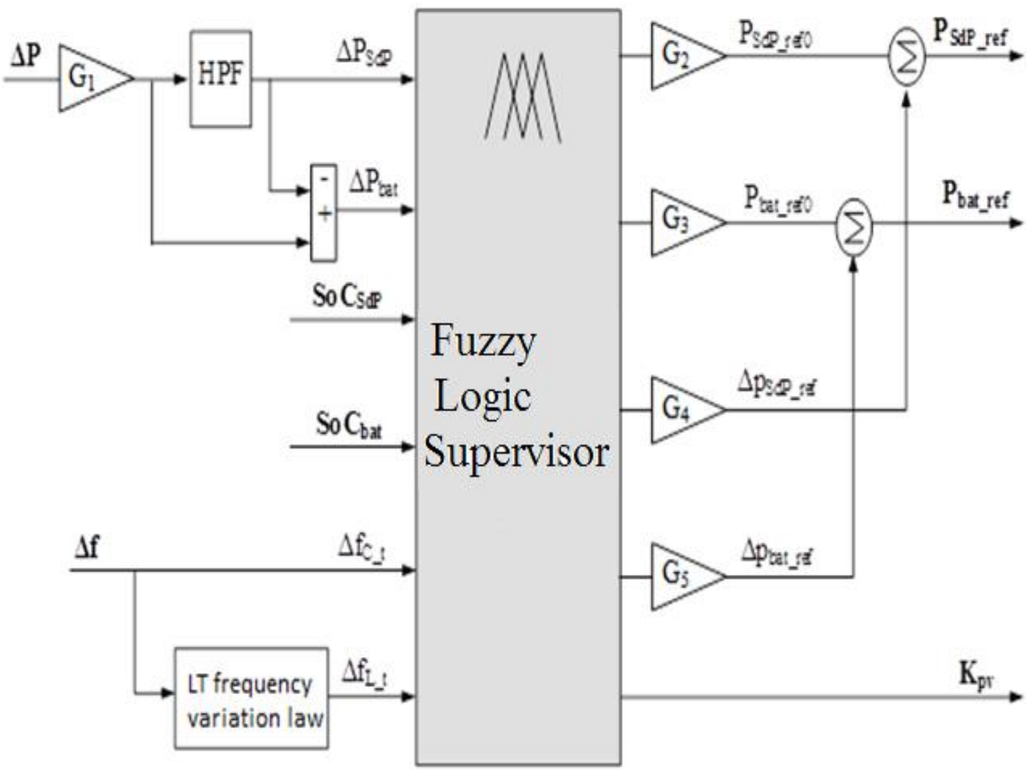
Energy management is made with a multi-step fuzzy logic methodology. It ensure several objectives at once (constraints and network services, storage levels and availability, lifespan and aging, etc.).In our case, flow management is intend to satisfy Day-1 production planning, to participate in frequency support and to protect storage elements monitoring their state of charge.

- Work specifications
- Design of the supervisor
- Chart representation of operating modes -Functional graphs -
- Determination of the membership functions
- Chart representation of fuzzy operating modes - Operational graphs -
- Determination of the fuzzy rules
- Determination of indicators to measure the achievement of objectives

Supervisor operating specifications

Objectives	Constraints	Actions
. Meet a production schedule ensuring injected power smoothness. **. Participate in frequency support (primary and secondary Supports).** **. Improve storage elements life by optimizing their management.**	**. PV production intermittency (amplitude and duration variations).** **. Storage elements size** **. Primary support in less than 500sec for 15 minutes. Response in less than 15 minutes for 30 minutes in case of secondary support. (Error of 0.5% with respect to the basic frequency 50 Hz).** **. The error on the production schedule :** **- Error margin on the production schedule: less than 10 % in middle hourly energy of the power plant compared with production program. Beyond this constraint, there is a risk that the photovoltaic producer loses his hour of production.** **- In case of excess or lack of energy injected according to that suited to Day-1 with the network administrator, the hour of production is lost.**	**. Two power storage references:** **- long-term (batteries), - short-term (power source: example: super-capacitors).** **. Degradation factor of photovoltaic production.**

Block diagram of the fuzzy supervisor



ΔP : Difference between planned and actual photovoltaic power production.

ΔP_{bat} and ΔP_{SdP} : respectively batteries and super-capacitors powers after filter separation.

SOC_{bat} and SOC_{SdP} : respectively batteries and super-capacitors State Of Charge.

Δf : Frequency variation with Δf_{C_t} for short term variations and Δf_{L_t} for long term ones.

P_{bat_ref} : Batteries reference power. It is the sum of two sub-outputs, initial reference P_{bat_ref0} and secondary support power frequency Δp_{bat_ref}.

P_{SdP_ref} : Storage power source (super-capacitors) reference. It is the sum of two sub-outputs, initial reference P_{SdP_ref0} and primary support power frequency Δp_{SdP_ref}.

$G_{i=1:5}$: Normalization gains. **HPF**: high pass filter (first-order filter). **K_{pv}**: PV production degradation factor.

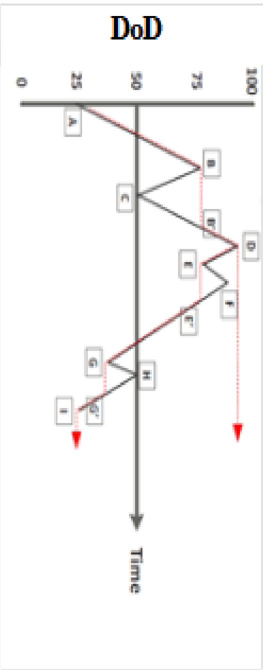
Supervision strategy functioning modes

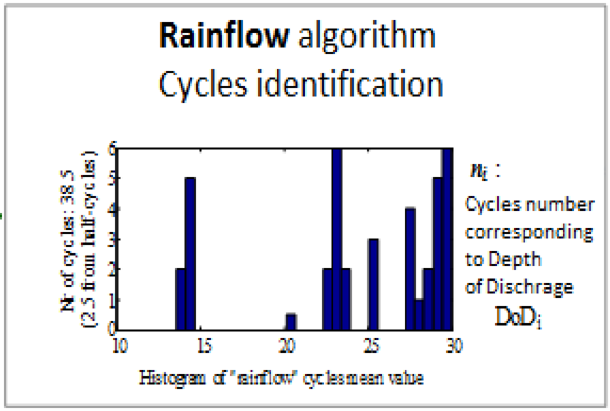
- **Normal or main mode (N1):** The SOC is medium or nominal (SOC_M) and the first aim of this mode is to meet the production program planned at day-1. The storage system has to fill the gap between the instantaneous power and photovoltaic production planned in day-1 while maintaining the functionality of power smoothing and frequency support.

- **Overcharge mode (N2):** This mode is dedicated to protecting storage system against the harmful effect of an overcharge on their lifespan. The principle is to minimize photovoltaic generation to discharge the storage elements until their nominal value.

- **Deep discharge mode (N3):** This mode is dedicated to protecting storage system against the harmful effects of deep discharge on their lifespan. The principle is to guarantee storage capacity by well preparing storage elements to production program. Ideally charge storage organs until their nominal value. Charge may be provided by photovoltaic production on the same day before beginning the production program (e.g. in a summer day) or directly from recharging via the grid.

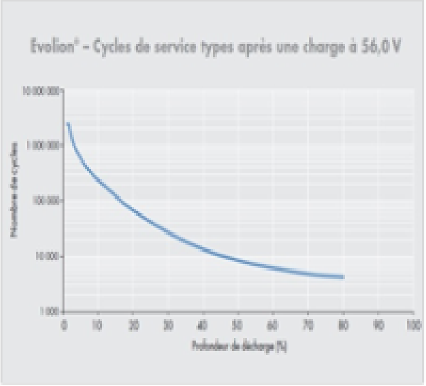
Principle of batteries deterioration calculating





Law of damage accumulation **(Miner):**

$$D = \sum (n_i/N_i)$$

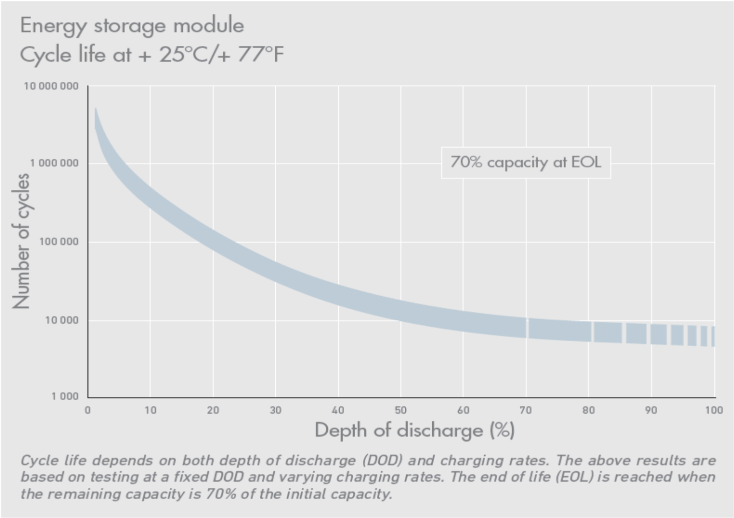


N_i :
Lifespan corresponding to amplitude DoD_i

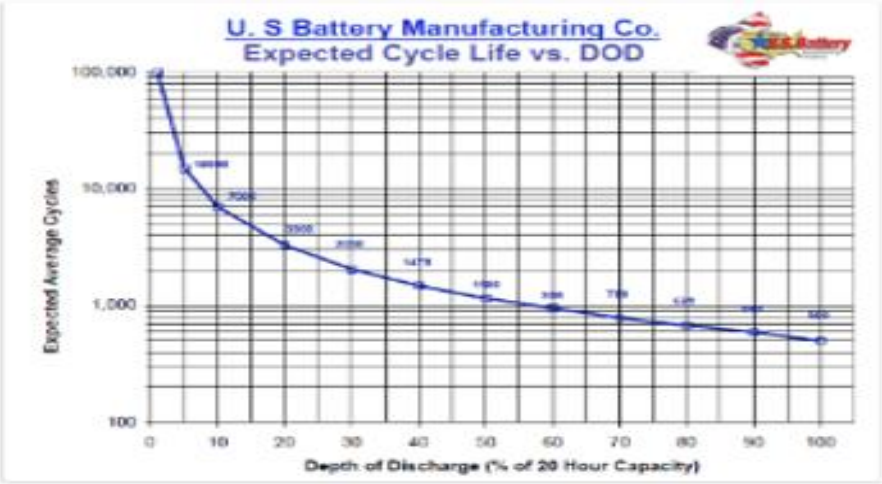
This method relies on two steps : The first step is the use of a cycle counting algorithm (Rainflow) that precisely identifies the parameters of a battery lifespan (number of cycles, deep cycles, standard cycles (complete or half cycles) and the periods of the cycles). The second step consists on using the aging curve of the storage component to identify its lifespan according to the respective cycles depths found in the first step

Aging curves of the different storage elements used in this work

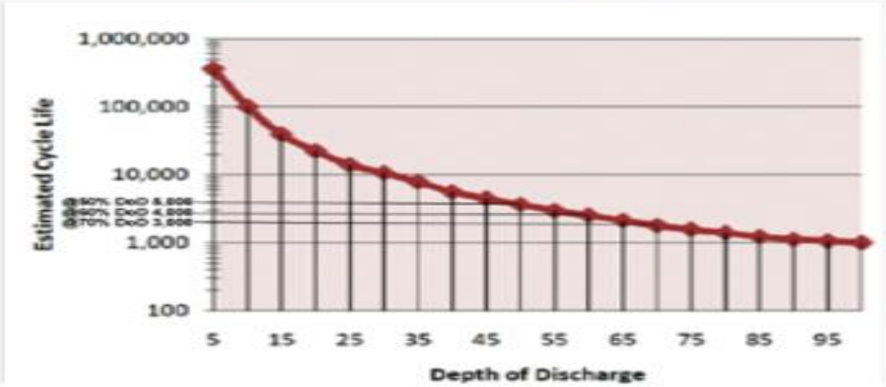
Battery Lithium NCA
(Lithium Nickel Cobalt Aluminium Oxid)



Nickel Metal Hybrid Battery
NiMH



Battery Lithium LiFePO4
(Lithium Fer Phosphate)



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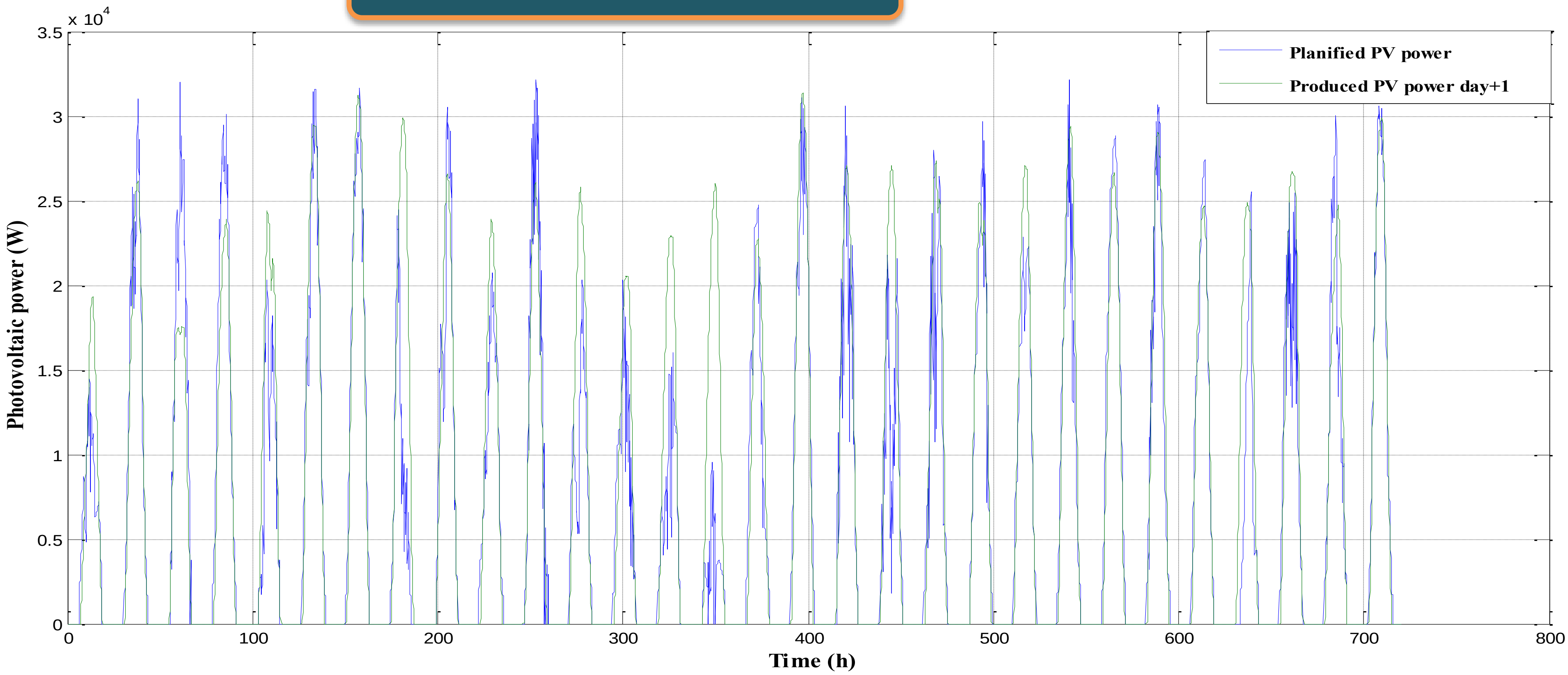
Photovoltaic power input data



Scenarios of photovoltaic generated and planned power correspond to forecasts at Day + 1 in a real site for year 2013. These data are collected on an hourly average. Realistic month profiles are considered with some modifications to incorporate effects of sudden weather changes.

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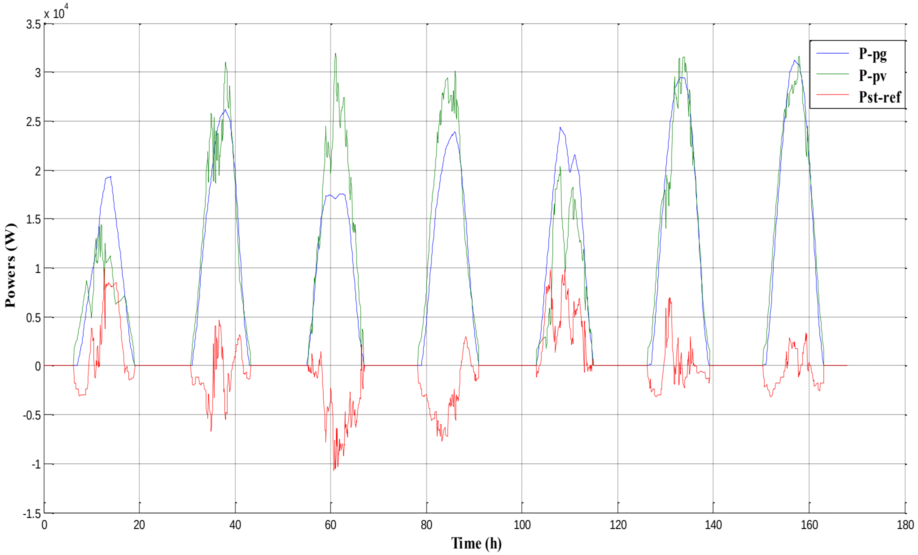
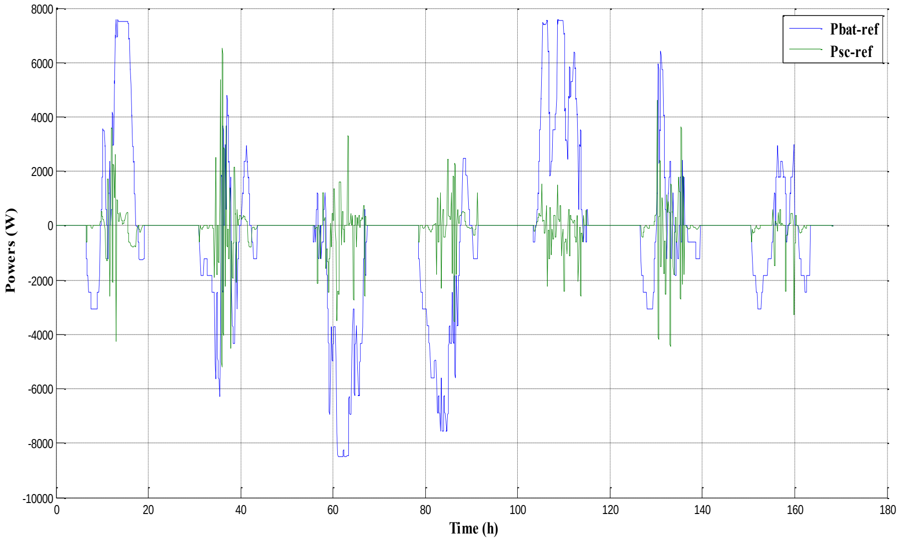
Supervisor validation

Scenarios Simulations are done according to these powers:
Photovoltaic source peak power: 30 kW.
Nominal NCA lithium batteries power (energy storage source): 6 kW (max power 8 KW).
Nominal power for storage power source (super-capacitors): 5kW (max power 9 KW) as transient peaks does not exceed the maximum power of 9 KW and for cost reasons.



Evolution of PV power plant powers on a week (30 KW PV+ 6 KW of batteries + 5 KW of super-capacitors)



Complementary operation between NCA lithium batteries and super-capacitors power storage source.

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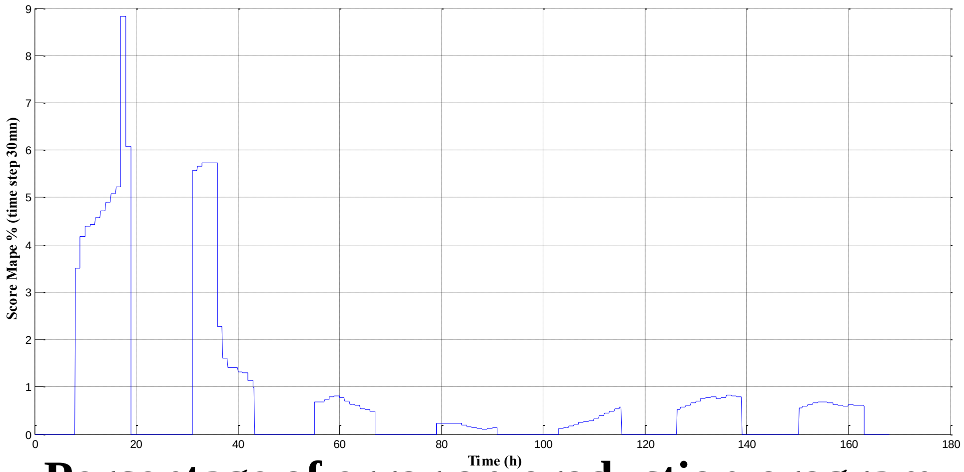
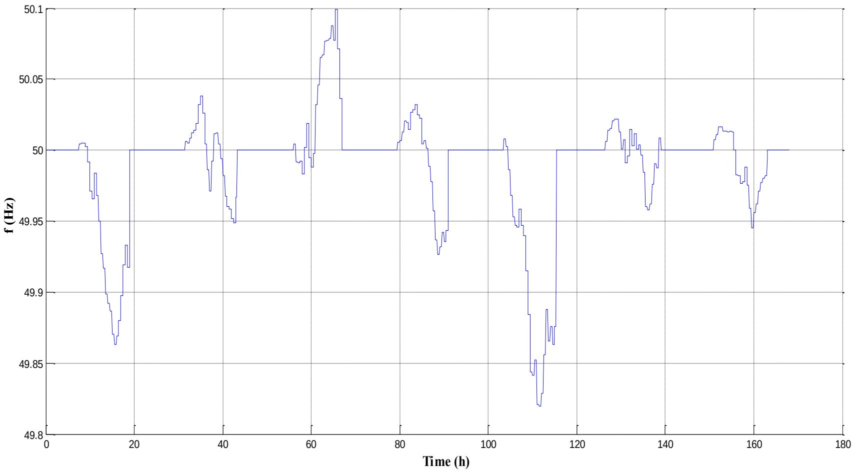
Supervisor validation



Percentage of error on production program satisfaction (MAPE score evaluated every 30 minutes).



Evolution of frequency every 15 minutes.

Percentage of error on production program satisfaction (MAPE score evaluated every 30 minutes) remains below 10 % for studied case.

Network support function reduces frequency variations amplitude.

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Storage elements lifespan assessment

To analyze the contribution of two-storage technologies combination, we propose to estimate storage system lifespan using the cumulative damage law along both configurations:

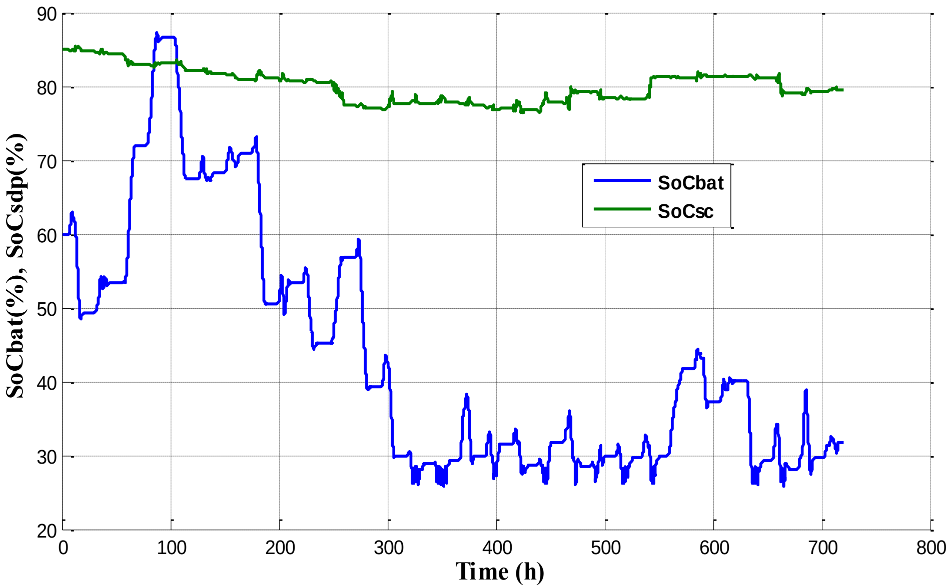
- **Batteries Lithium NCA in combination with different power storage sources :**
  - Batteries NiMH;
  - Batteries Lithium Li Fe $PO_{4;}$
  - SuperCaps Maxwell.

Powers: Batteries Lithium NCA of 6 kW, 7.5 KW, 15 KW and 22.5 KW and power storage source of 5 KW (max power 9 KW) as transient peaks does not exceed the maximum power of 9 KW and for cost reasons. The peak power of the photovoltaic system is 30 kW.

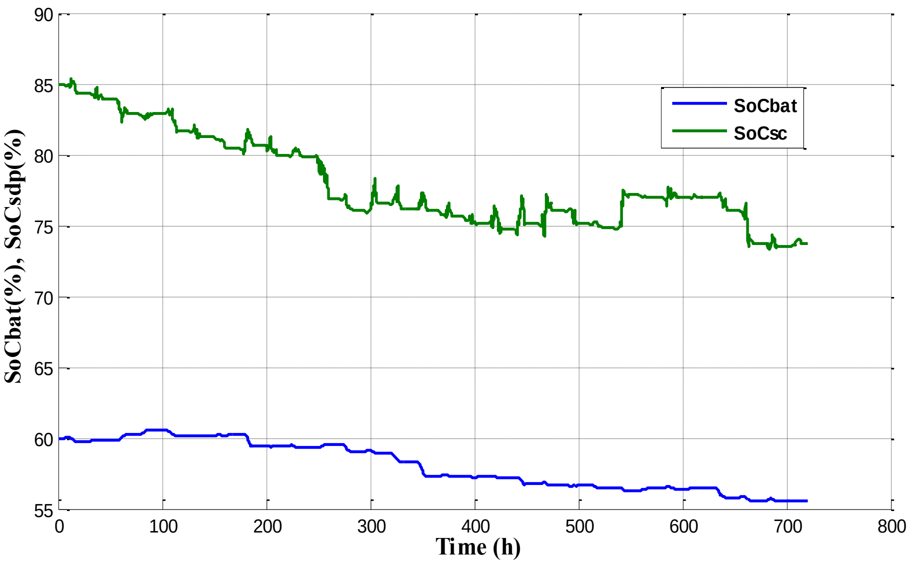
- **Batteries lithium NCA only : 6 kW, 7.5 KW, 15 KW and 22.5 KW**

  The peak power of the photovoltaic system is 30 kW.

Storage elements lifespan assessment



Evolution of SoC level: batteries lithium NCA 6 kW and power storage source 5 kW



Evolution of SoC level: batteries lithium NCA 22.5 kW and power storage source 5 kW.

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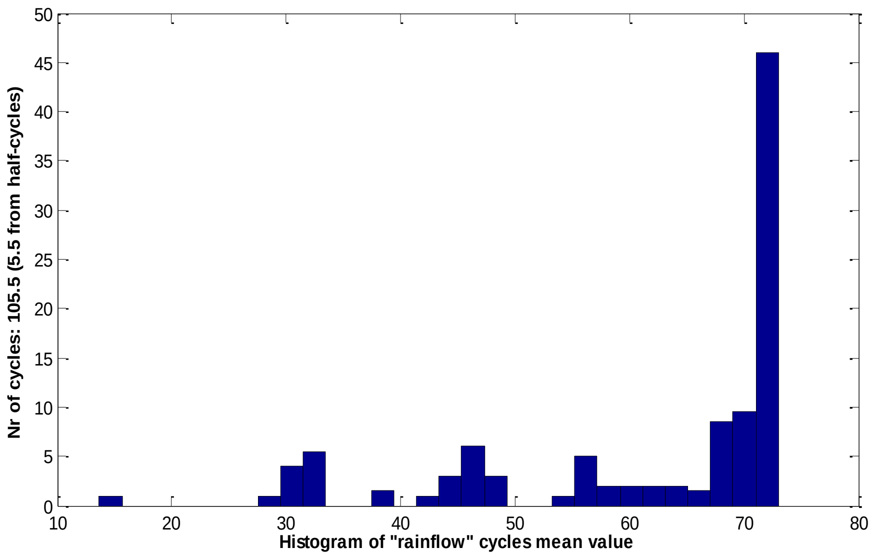
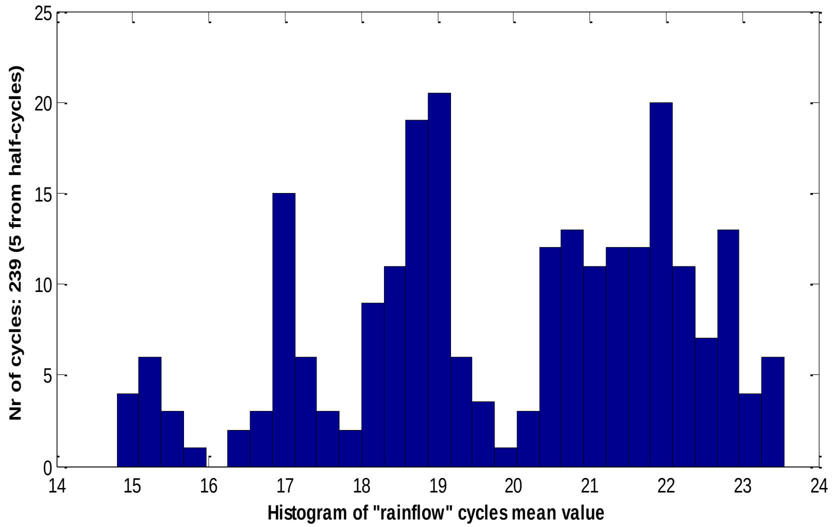
Storage elements lifespan assessment



Number of batteries cycles vs DoD_i : batteries lithium NCA 6 KW



Number of batteries cycles vs DoD_i : storage power source 5 kW

Storage elements lifespan assessment

Batteries power (KW)	Power storage sources (KW)	Period (hours / month) of tolerated frequency error (0.5%) violation	Battery Lifespan (years) (70% degrada-tion)	Storage source lifespan (years) (70% degradation)
6	0	56.6	4.9	-------
7.5	0	49.14	5	-------
15	0	1.5	11	--------
22.5	0	0	22.4	--------
6	5	53.6	5.5	Bat. NIMH : 0.9 Bat. FePO4 : 6.2 Supercap : > 25
7.5	5	44.6	6	Bat. NIMH : 0.9 Bat. FePO4 : 6.1 Supercap : > 25
15	5	2.5	13.6	Bat. NIMH : 0.8 Bat. FePO4 : 5.4 Supercap : > 25
22.5	5	0	25	Bat. NIMH : 0.8 Bat. FePO4 : 5.1 Supercap : > 25

Comparative table of the different storage technologies lifespan for various hybridization scenarios

Results

- System sizing is crucial. It influences batteries life time and frequency regulation. There must be installed a few rapid storage power for peaks and lots of batteries.

- The life of the power source decreases slightly by increasing batteries power because of more frequency regulation with primary support (refer to period (hours / month) of tolerated frequency error (0.5%) violation last table).

- The increase in batteries power smooths their charge discharge curve and consequently decreases their DoD thus improves their durability.

- Adding a power storage source to absorb the peaks improves batteries life but it may be better to oversize batteries than make hybridization. Unless, there must be installed a few rapid storage power for peaks and lots of batteries.

Results

- According to the last table, to have a good frequency adjustment with respect of the production program, a power storage> = 50% installed PV power must be used.
- Batteries NIMH are not adequate for hybridization. They have a very short lifespan.
- Batteries FePO4 and super-capacitors are recommanded for hybridization. However, they have totally different lifespans and costs, so a life cycle cost analysis should be made to help designers in their choice.
- The comparative table II can be considered as a design aid tool. For example, we can opt for a system of 30 KW PV, 15 KW Batteries, 5 KW supercap. The final choice of course will require a rigorous analysis of the life cycle cost of the chosen solution.
- Finally, the results depend strongly on the photovoltaic production profile and the quality of forecasts. They should be taken with great care.

Perspectives

In our future work, we propose to validate the developed energy management fuzzy logic method on a test bench with a realistic reproduction in terms of powers and emulation time. We also propose to focus on the optimal design of the system taking into account the satisfaction of grid constraints in addition to life cycle economic costs and levelized cost of energy.

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