Power management of an islanded DC MicroGrid

SESO 2018 International Thematic Week
Smart Energy and Stochastic Optimization

Alessio Iovine, Tristan Rigaut, Gilney Damm,
Elena De Santis, Maria Domenica Di Benedetto

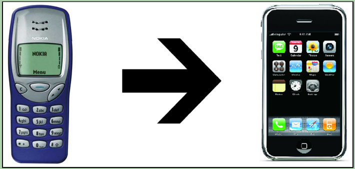
Efficacity, Paris-Saclay University, L'Aquila University

Paris, May 24th 2018

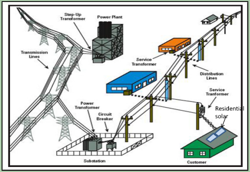
Index

What is a SmartGrid?

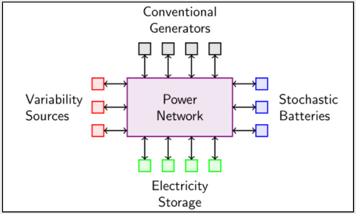
Phone ⇒ Smartphone

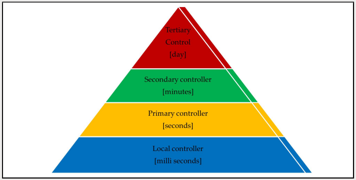


Grid ⇒ SmartGrid

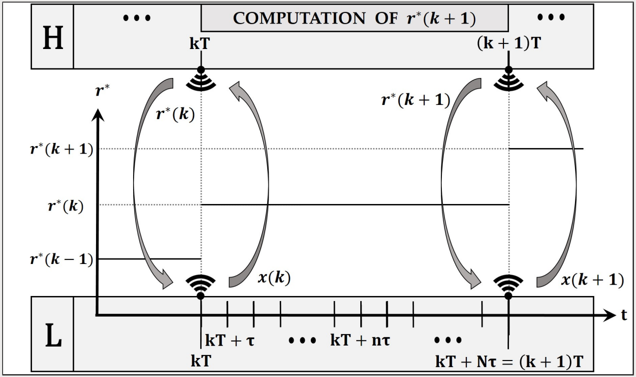


Power Systems Control





Link between levels



DC MicroGrid

Definition

Microgrid concept: a cluster of loads and microsources operating as a single controllable system that provides power to its local area.

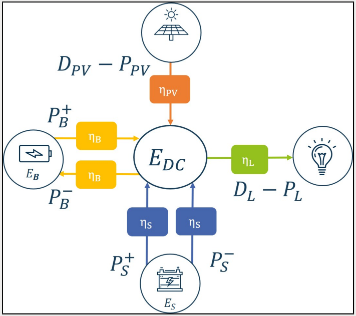
The **typical DC Microgrid** consists of:

- variable generations (PVs, wind turbines);
- controlled generations (AC grid connection);
- variable loads;
- energy storage systems (batteries, supercapacitors).

Secondary level controller

MicroGrid: a set of energy nodes and power edges

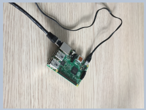
- E_B, E_S, E_{DC} are the energies stored in the battery, supercapacitor and DC grid
- $D_{PV} - P_{PV}$, $D_L - P_L$, P_B^+, P_B^-, P_S^+, P_S^-, are the exchanged powers



Stochastic problem?

Target

To implement the power flow optimization problem in a low cost hardware.



Problem

Stochastic methods lack of simplicity!

Too computationally expensive!

$$\min_{u(\cdot)} \mathbb{E} \sum_{k=0}^{\infty} f(x(k), u(k))$$

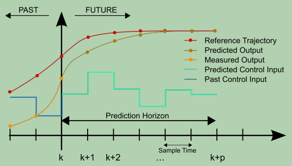
Stochastic problem?

Assumption

Over a finite and sufficiently short time horizon the high-level system **H** is able to compute good forecasts of the demand and solar power.

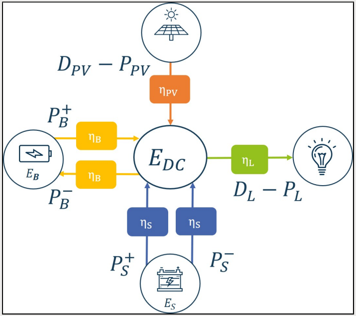
Solution

Deterministic control strategy: MPC



Model

$$\begin{cases} E_{DC}(k+1) = E_{DC}(k) + T\left[\eta_{PV}(D_{PV}(k) - P_{PV}(k))\right] + \\ \qquad -T\left[\frac{1}{\eta_L}(D_L(k) - P_L(k))\right] + \\ \qquad +T\left[\eta_B P_B^+(k) - \frac{1}{\eta_B}P_B^-(k) + \eta_S P_S^+(k) - \frac{1}{\eta_S}P_S^-(k)\right] \\ E_B(k+1) = E_B(k) + T\left[-P_B^+(k) + P_B^-(k)\right] \\ E_S(k+1) = (1 - T\alpha_S)E_S(k) + T\left[-P_S^+(k) + P_S^-(k)\right] \end{cases}$$



Model

$$\begin{cases} E_{DC}(k+1) = E_{DC}(k) + T\left[\eta_{PV}(D_{PV}(k) - P_{PV}(k))\right] + \\ \qquad -T\left[\frac{1}{\eta_L}(D_L(k) - P_L(k))\right] + \\ \qquad +T\left[\eta_B P_B^+(k) - \frac{1}{\eta_B} P_B^-(k) + \eta_S P_S^+(k) - \frac{1}{\eta_S} P_S^-(k)\right] \\ E_B(k+1) = E_B(k) + T\left[-P_B^+(k) + P_B^-(k)\right] \\ E_S(k+1) = (1 - T\alpha_S)E_S(k) + T\left[-P_S^+(k) + P_S^-(k)\right] \end{cases}$$

$$x(k+1) = Ax(k) + Bu(k) + Dd(k)$$

$$x = [E_{DC}\ \ E_B\ \ E_S]' = [x_1\ \ x_2\ \ x_3]'$$

$$u = [P_{PV}\ \ P_L\ \ P_B^+\ \ P_B^-\ \ P_S^+\ \ P_S^-\ ]' = [u_1\ \ u_2\ \ u_3\ \ u_4\ \ u_5\ \ u_6]'$$

$$d = [D_{PV}\ \ D_L]' = [d_1\ \ d_2]'$$

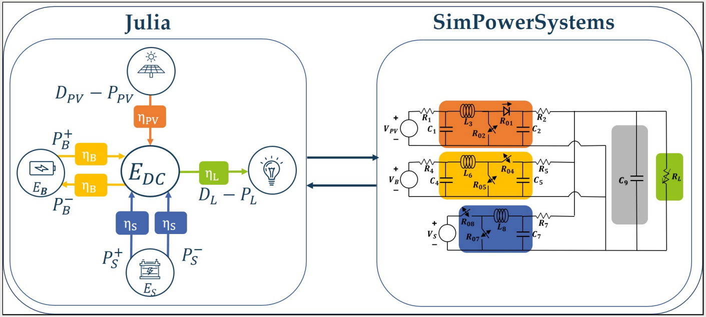
Mixed Integer Quadratic Program

$$\min_{u(\cdot)} \quad \frac{1}{2}\left[\tilde{x}(k+\mathcal{N})^T P \tilde{x}(k+\mathcal{N}) + \sum_{i=k}^{k+\mathcal{N}-1} \tilde{x}(i)^T Q \tilde{x}(i) + u(i)^T R u(i)\right]$$

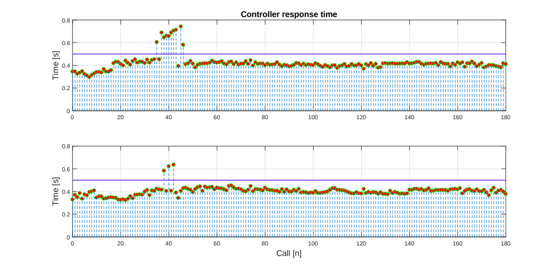
$$\begin{aligned}
\text{s.t}\quad & \tilde{x}(i) = x(i) - x^r(i),\ \forall\, i \\
& x(i+1) = Ax(i) + Bu(i) + Dd(i),\ \forall\, i \\
& x(k) = x_0(k), \\
& x_j^m \le x_j(i) \le x_j^M, j = 1,2,3,\ \forall\, i \\
& S_B(i) \in \{0,1\},\ \ S_S(i) \in \{0,1\},\ \forall\, i \\
& 0 \le u_1(i) \le d_1(i),\ \ 0 \le u_2(i) \le d_2(i),\ \forall\, i \\
& u_3(i) \le S_B(i)\cdot \overline{P}_B^+,\ \ u_4(i) \le (1 - S_B(i))\cdot \overline{P}_B^-,\ \forall\, i \\
& u_5(i) \le S_S(i)\cdot \overline{P}_S^+,\ \ u_6(i) \le (1 - S_S(i))\cdot \overline{P}_S^-,\ \forall\, i \\
& \|u_3(i+1) - u_3(i)\| \le \Delta\overline{P}_B^+,\ \ \|u_4(i+1) - u_4(i)\| \le \Delta\overline{P}_B^+,\ \forall\, i
\end{aligned}$$

MIQP problem can be reformulated as a Mixed Integer Second Order Cone Program (MISOCP)

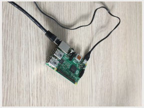
Simulations



Simulations

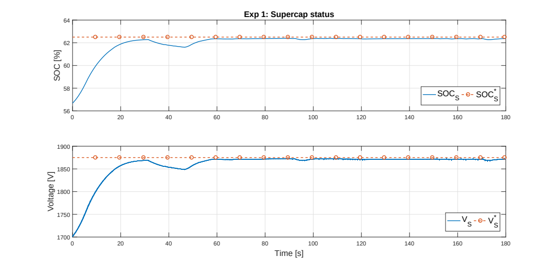


The power management controller response time for the considered cases when implemented in the Raspberry Pi.

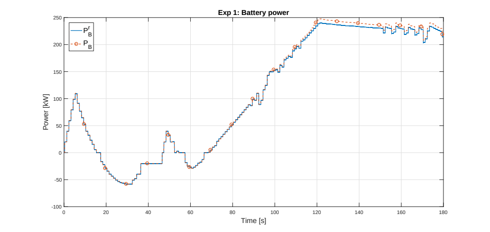


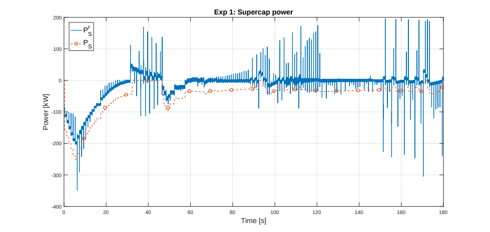
Experiment 1

Exp 1: The supercapacitor needs to recharge

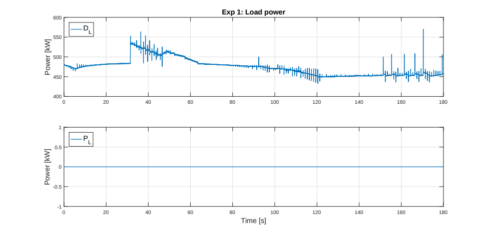


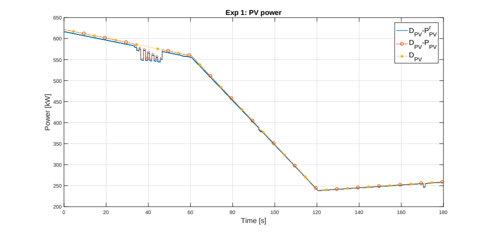
The SOC and voltage of the supercapacitor (blue line) with respect to their reference values (dotted red line).





The optimal values for the powers of the two storages (battery and supercap).

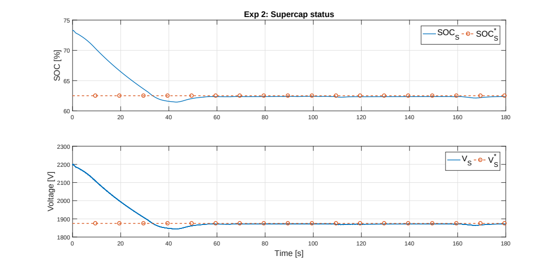




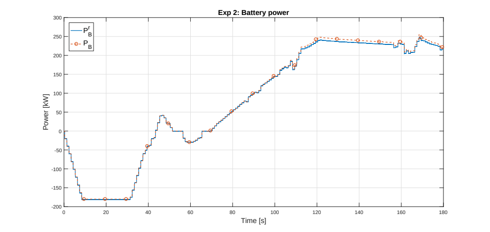
The optimal values for the powers of the PV and of the load.

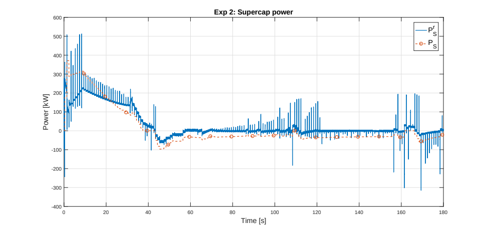
Experiment 2

Exp 2: The supercapacitor needs to discharge

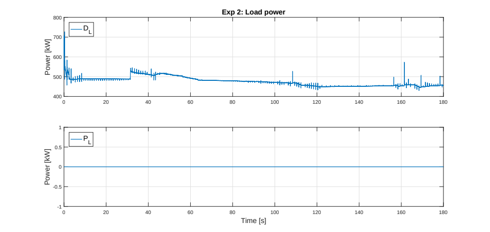


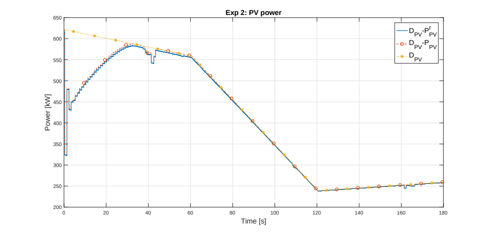
The SOC and voltage of the supercapacitor (blue line) with respect to their reference values (dotted red line).





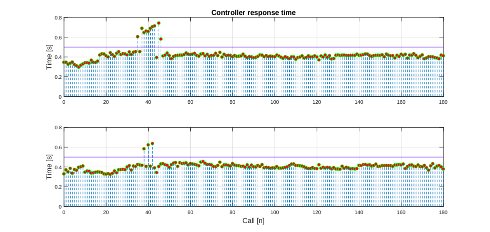
The optimal values for the powers of the two storages (battery and supercap).

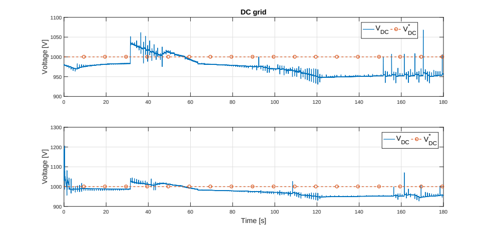




The optimal values for the powers of the PV and of the load.

Simulations





The DC grid voltage.

Results

Main result

Realistic stable DC Microgrid development, considering a power flow control for energy balancing purposes.

Future researches

I. Economic optimization (3rd layer);
II. Decentralized optimal control for a more complex grid.

Info

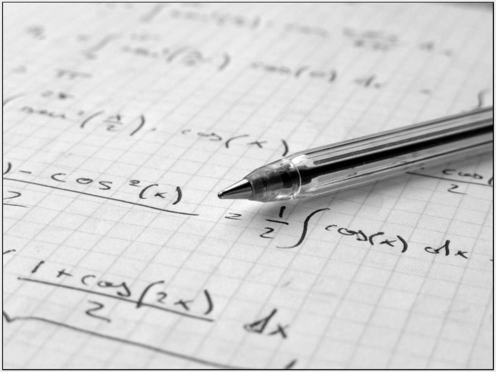
Related publications

- A. Iovine, G. Damm, E. De Santis, M. D. Di Benedetto, *Management Controller for a DC MicroGrid integrating Renewables and Storages*, IFAC World Congress, July 10-14, 2017, Toulouse, France, in IFAC-PapersOnLine, Volume 50, Issue 1, 2017.
- A. Iovine, T. Rigaut, G. Damm, E. De Santis, M. D. Di Benedetto, *Power Management for a DC MicroGrid integrating Renewables and Storages*, submitted.

Contacts

Alessio Iovine
a[dot]iovine[at]efficacity[dot]com
Efficacity

Thanks for your attention!



Any Questions?