

Maximisation of self-consumption of PV power

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1 Introduction

2 Problem statement

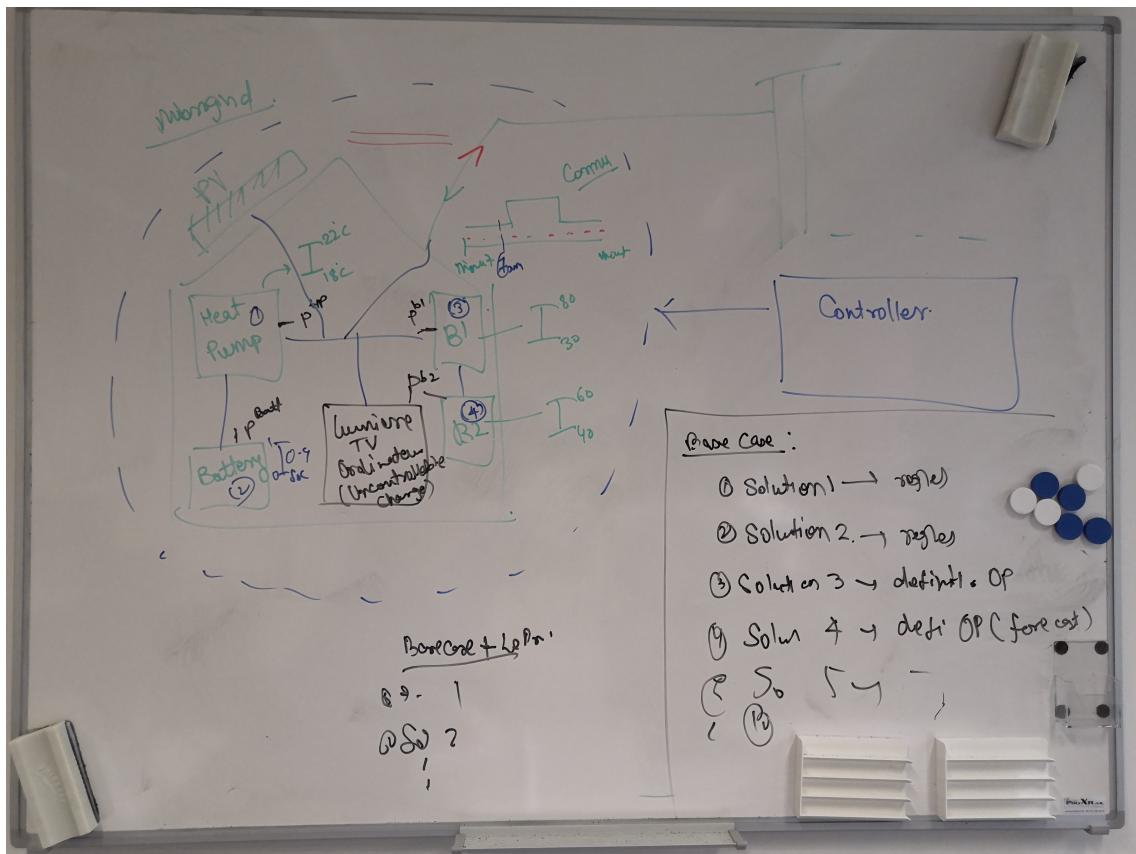


Figure 1: Microgrid sketch (to be changed afterwards)

2.1 System description

The object of the study is a microgrid connected to the distribution grid. In the present case, we consider a simple microgrid that can be seen as a domestic household equipped with a PV system. Because of its power generation capacity, the microgrid can inject excess power into the grid via a single two-ways connection.

As for the energy consumption of the household, this one can be divided in two well defined classes: controllable and non-controllable loads. The former describes all appliances that are human-switched (TV, lights, coffee machine, etc.). The present makes reference to those flexible loads which power consumption can be blabla:

To ensure thermal comfort, the household is equipped with two boilers and a heat pump (HP). An energy storage system (battery).

The objective of the energy management strategy is to control the flexible loads in order to maximise self-consumption and reduce electricity costs. The list of necessary sensors/actuators to enable such Energy Management System (EMS) will be described further down.

2.2 Modelling of the various components

The defined control strategies of the energy management system will handles discrete quantities. From 0 to H , the index h refers to current time period.

PV system

p_{PV} : PV output power after inverter's MPPT algorithm.

Energy storage system

Control variable (s):

u_b : Battery power (kW). Negative if battery is charging, positive if discharging.

Measured parameters:

$p_b^{measured}$: Measured battery power x_b : Battery charge state (kWh)

Constant parameters:

\bar{C}_b : Max. battery capacity (kWh)

\underline{C}_b : Min. battery capacity (kWh)

\bar{P}_b : Max. charging power of the battery (kW)

\underline{P}_b : Max. discharging power of the battery (kW)

The variable u_b (kW) influences the State-Of-Charge (SOC) of the battery:

$$x_b[h+1] = (x_b[h] + u_b^+[h] + u_b^-[h]) dt \quad (1)$$

$$u_b[h] = u_b^+[h] + u_b^-[h] \quad (2)$$

Battery charging/discharging power and capacity are physically limited. In order to ensure that $u_b^+[h]$ and $u_b^-[h]$ are not simultaneously non-null, binary variables $s_b[h]$ are injected in the constraints:

$$\underline{C}_b \leq x_b[h] \leq \bar{C}_b \quad (3)$$

$$0 \leq u_b^+[h] \leq s_b[h] \bar{P}_b \quad (4)$$

$$0 \geq u_b^-[h] \geq (1 - s_b[h]) \underline{P}_b \quad (5)$$

Initialization:

To avoid any distortion of results, the amount of energy stored within the battery at the initial time-step must be set as equal to the last:

$$x_b[0] = x_b[H] \quad (6)$$

Open parenthesis More accurate battery model for further study:

(α_b : Battery leakage coefficient (s^{-1}))
 $(\eta_b^+, \eta_b^-$: Battery charging and discharging efficiency)

The continuous variable u_b (kW) influences the State-Of-Charge (SOC) of the battery. An integrative model describes the SOC evolution [?]:

$$x_b[h+1] = (\alpha_b x_b[h] + \eta_b^+ u_b^+[h] + \frac{1}{\eta_b^-} u_b^-[h]) dt \quad (7)$$

$$(8)$$

Close parenthesis

Thermo-electric loads

The storage capacity from thermo-electric units, like electric boilers (B) and heat pumps (HP), allows operating them with certain freedom. Hence they can be employed under certain coordination, to actively respond to the power system fluctuations.

$\underline{P}_{B,k}^{B,k}$ Min. power of electric boiler k (kW)
 $\bar{P}_{B,k}^{B,k}$ Max. power of electric boiler k (kW)
 \underline{P}_{HP}^{HP} Min. power of electric heat pump (kW)
 \bar{P}_{HP}^{HP} Max. power of electric heat pump (kW)

$$\underline{P}^{B,k} \leq p^{B,k}[h] \leq \bar{P}^{B,k} \quad (9)$$

$$\underline{P}^{HP} \leq p^{HP}[h] \leq \bar{P}^{HP} \quad (10)$$

$$(11)$$

(For future extension of the problem set and for syntax purposes, it would be nicer to define a power vector $\hat{\mathbf{p}}^c[h]$ for all the N_c controllable thermo-electric units. But maybe mixing B and HP will complicate things in MPC when handling with hot water consumption forecasts and outside temperature forecasts.)

Building comfort constraint must be respected and indoor temperature $T[h]$ must remain within a band around min and max temperature bounds (\underline{T}, \bar{T}) . When the system temperature approaches one of the bounds (with a certain tolerance ϵ_T). Let's also define the target temperature T^{set} as $\frac{\underline{T}+\bar{T}}{2}$.

As for the boilers, flexibility is again achieved by imposing upper and lower limits to the hot-water temperature $(\underline{T}^{B,k}, \bar{T}^{B,k})$. Power injections into the thermo-electric units are also constrained:

$$p^{B,k}[h] \leq \bar{P}^{B,k} \quad (12)$$

$$p^{HP}[h] \leq \bar{P}^{HP} \quad (13)$$

$$(14)$$

The structure/vector $\hat{\mathbf{x}}^c[h]$ regroups the state of the N_c controllable thermo-electric units. From a controller device perspective, it is assumed that a pre-processing unit is handling thermal sensors outputs and normalizing them according to upper and lower limits of each load.

3 Control strategy

3.1 Principles

$C[h]$ is a global variable, known by the control system.

The microgrid automatically balances power supply and demand. We assume any PV generated power not consumed by the building is absorbed by the grid without the necessity of any control action. Similarly, any power demand from loads that cannot be supplied by the PV system is supplied by the grid.

The following control strategy is designed to manage controllable (flexible) loads. Hence, only five control variables are in play : s_b , u_b^+ and u_b^- , $p^{B,k}$, p^{HP} .

3.2 Strategy 1

The controller is configured by establishing rules determined by all possible system operating scenarios. Those logic constraints are:

1 - For feeding uncontrollable loads, PV power is the prior source, followed by battery storage and finally the main grid.

2 - As the only internal power generation source, PV system feeds storage battery and controllable loads with certain priority rules:

2.1 - ESBS has priority until 80% SOC is reached. An hysteresis control charges the battery until 80% SOC and lets it progressively discharge until 70% SOC.

2.2. Second in the priority ladder, controllable loads with the lower energy levels (normalized) are charged.

The variable $p_x = p_{PV} - p_{nc}$ refers to the excess PV power in the microgrid available to feed controllable loads. When such excess is negative, charging such loads demands electricity from the main grid.

Algorithm 1: How to write algorithms

Result: Write here the result
initialization;
for *While condition do*
 instructions;
 if *condition then*
 instructions1;
 instructions2;
 else
 instructions3;
 end
end

Algorithm 2: : Lower constraint handling

Executed every time-step h;

Inputs: $x_b[h-1], x_b[h], T_{B1}[h], T_{B2}[h], T_{HP}[h], p_{PV}[h], p_{nc}[h]$, Control variables: p_{B1}, p_{B2}, p_{HP}
or just $\hat{p}^c[h]$

start

$p_x = p_{PV}[h] - p_{nc}[h]$

for each energy system k in ($B1, B2, HP$) **do**

if $T^k[h] \in [\underline{T}^k; \overline{T}^k + \epsilon_{T,k}]$ **then**

if $p_x > 0$ **then**

$p^k \leftarrow \min(p_x, \overline{P}^k)$

; if excess ($p_x > p^k$) **then**

$p_x = p_x - \overline{P}^k$

 gerer l'exces

end

else

$p^k \leftarrow \overline{P}^k$

end

end

end

update Control Variables

call Algorithm 2 ($p_x, x_b[h-1], x_b[h], T_{B1}[h], T_{B2}[h], T_{HP}[h]$)

We could handle the excess/surplus inside the constraint loop, but easier visualization if we present a second Algorithm for doing so:

Algorithm 3: : Treatment of microgrid's excess power

Executed for the time-step h

Inputs: $p_x, x_b[h - 1], x_b[h], T_{B1}[h], T_{B2}[h], T_{HP}[h]$ Control variables: u_b, s_b, p_B, p_{HP}

if $p_x > 0$ **then**

if $(x_b[h] < 0.8(\bar{C}_b - \underline{C}_b))$ **and** $(x_b[h] > x_b[h - 1])$ **then**
 | $s_b \leftarrow 1$ (Battery in charging mode)
 | **if** $(\underline{P}_b \leq p_x[h] \leq \bar{P}_b)$ **and** $(x_b[h] + p_x \times dt \leq \bar{C}_b)$ **then**
 | | $u_b \leftarrow p_x[h]$
 | | **end**
 | **if** $(p_x[h] > \bar{P}_b)$ **and** $(x_b[h] + p_x \times dt \leq \bar{C}_b)$ **then**
 | | $u_b \leftarrow \bar{P}_b$ call *PriorityChargingFlexibleLoads*($p_x = p_x[h] - \bar{P}_b$) (Algorithm 3)
 | | **end**
 | **if** $(x_b[h] + p_x[h] \times dt > \bar{C}_b)$ **and** $(\underline{P}_b \leq p_x[h] \leq \bar{P}_b)$ **then**
 | | $u_b \leftarrow \bar{C}_b - x_b[h]$
 | | **end**
 | **else**
 | | $u_b \leftarrow 0$
 | **end**

end

if $(x_b[h] > 0.7(\bar{C}_b - \underline{C}_b))$ **and** $(x_b[h] \leq x_b[h - 1])$ **then**

| call *PriorityChargingFlexibleLoads*(p_x) (Algorithm 3)

end

end

else

$s_b \leftarrow 0$
if $x_b[h] + p_x[h] \times dt > \underline{C}_b$ **then**
 | **if** $\underline{P}_b \leq |p_x[h]| \leq \bar{P}_b$ **then**
 | | $u_b \leftarrow |p_x[h]|$
 | | **end**
 | **if** $|p_x[h]| > \bar{P}_b$ **then**
 | | $u_b \leftarrow \bar{P}_b$
 | | **end**

end

end

update control variables

Algorithm 4: Controllable loads priority rules

Inputs: $p_x[h]$, $\hat{x}^c[h]$ Control variables: $\hat{p}^c[h]$

normalize $\hat{x}^c[h]$

sort $\hat{x}^c[h]$ in increasing order

for $k \in N_c$ do

if $x_k^c \in [1 - \Delta T_k; 1]$ then

| break;

end

$p^k \leftarrow \min(p_x, \bar{P}^k)$

$p_x = p_x - p^k$

if $p_x \leq 0$ then

| break;

end

end

3.3 Strategy 2: accounting for grid's electricity prices

When the "get ready" phase starts, if PV is at low power states, the battery and the controllable loads will be charged by the main grid.//

During high priced period, controller configuration will be back to normal.

Let's define the maximum time t_c^b needed to charge the battery from the lowest energy level to the highest.

$$t_c^b = \frac{\bar{C}_b^k - C_b^k}{\bar{P}_b}$$

In the same way, $t_c^{B,k}$ and t_c^{HP} are maximum charging times for B and HP. The maximum time t_c needed to charge all appliances is hence defined as:

$$t_c = \max(t_c^b, t_c^{B,k}, t_c^{HP})$$

3.4 Strategy 3: fuzzy logic

Primero explicar el problema de la 1, que creo que es que si el PV power varia de un timestep a otro, no hay manera perfecta de considerar sea variacion ya que el modo de funcionamiento es ON/OFF. En cambio, con fuzzy logic , hay una serie de valores entre [0,1] (discretos pero mas continuos que on/off).