Microgrids

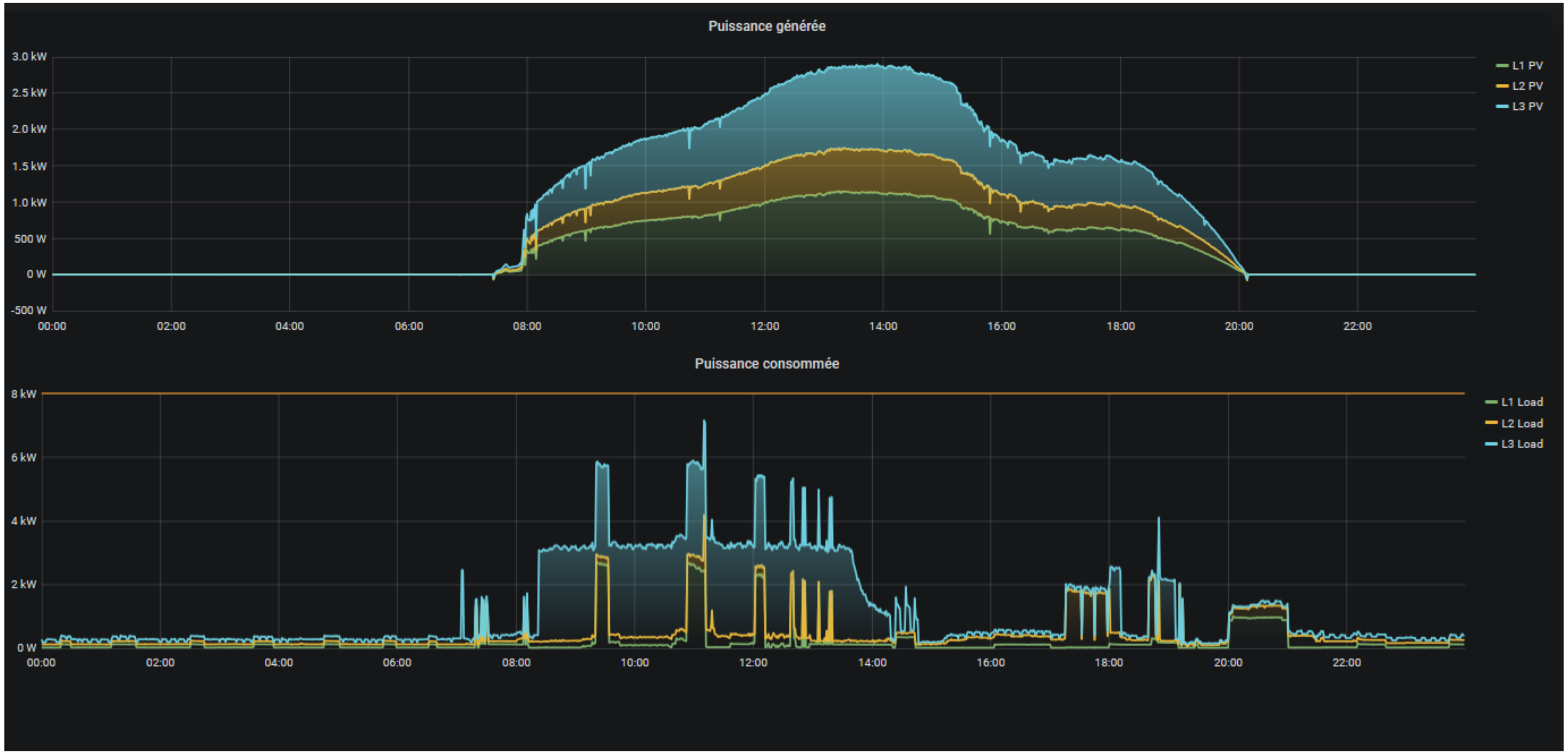
ELEN0445

Operational planning

Introduction

LIÈGE université
Sciences Appliquées


3.0 K
2.5 K
2.0 K
1.5 K
1.0 K
500
0
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
L1 Load
Load
2.5 K
2.0 K
1.5 K
1.0 K
500
0
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
L2 Load
Load
4.0 K
3.0 K
2.0 K
1.0 K
0
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
L3 Load


Puissance générée
3.0 kW
2.5 kW
2.0 kW
1.5 kW
1.0 kW
500 W
0 W
-500 W
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
L1 PV
L2 PV
L3 PV
Puissance consommée
8 kW
6 kW
4 kW
2 kW
0 W
L1 Load
L2 Load
L3 Load

Content of this lecture

- We take the role of the operator of the microgrid, who wants to optimize the way the energy is produced and used within the microgrid, and to optimize the interaction with the public grid (simple interaction, e.g. varying price).

- We make the assumptions that the microgrid is single-user, and we also avoid the question of the “fast dynamics” of the components of the microgrid.

Reminder: control levels

Level	Function	Examples
1	Device level control	BSS control, reactive control
2	Local area control	Frequency regulation, fast load shedding
3	Supervisory control	Forecasting, operational planning
4	Public Grid interaction	Ancillary services, energy markets

We will be mainly focused on levels 3 and 4, and a bit about level 2

In this lecture: level 3 & centralized control

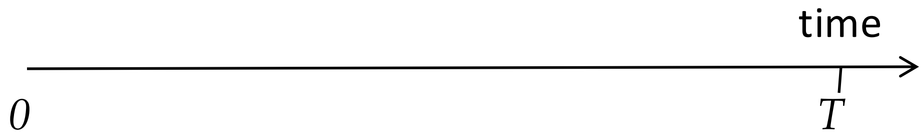
Operational planning

When are operation decisions taken?

- It can be in real time: corrective decisions
- Or in anticipation: **preventive** decisions
- Why should we anticipate? because of time coupling constraints:
  - The typical periodicity of renewable generation devices and consumption is a day
  - Human activity has daily, weekly and seasonal periodicity

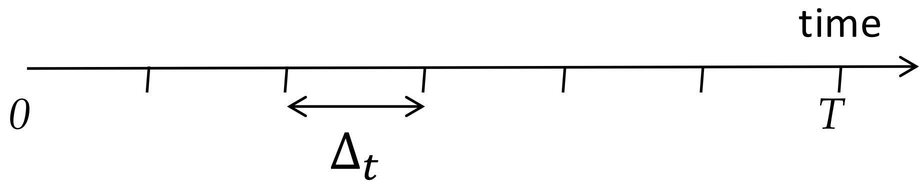
Operational planning decision horizon T

- We cannot take preventive operation decisions too much in advance:
  - too high uncertainty on the evolution of the state of the microgrid and its environment
  - anticipating a bit on the sequel, the problem we will have to solve may be intractable
- We thus consider operating the system over one day to approx. one week. This can be more or less, depending on the particular situation of the microgrid (type of storage, type of business activity, etc.)



Operational planning decision duration Δ_t

- For computational reasons, we **discretize** the decisions in time
- Depending on the decision horizon, we may consider periods of 1 to 15 minutes where decisions are assumed constant
  - Example: constant charge power for a battery
  - Determining good decisions may become intractable if we have too many decisions in the decision horizon
  - Forecasts may anyway not be meaningful with a too high temporal resolution
  - This is coherent with market period duration

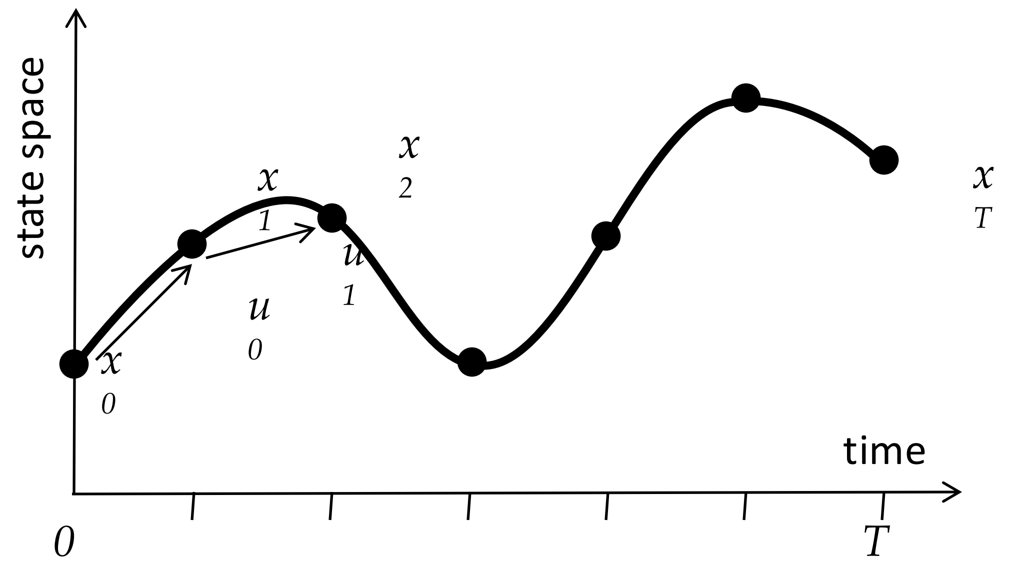


Operation as a sequential decision-making problem

We have a discrete-time system represented by a **state** x_t

$x = (x_0, x_1, \ldots, x_T)$ *represents the* ***state evolution*** *of the system*

$u = (u_0, \ldots, u_{T-1})$ *is a* ***sequence of control actions*** *(decisions)*



Given a criterion, we can compute an open-loop sequence of actions u^* to drive the system

We estimate demand, generation, availability of system components, etc. and then solve

minimize cost of u

subject to 1. balance generation and demand $\forall t \in \{1, 2, \ldots, T\}$

2. dynamics: $x_{t-1}, u_{t-1} \rightarrow x_t \ \forall t \in \{1, 2, \ldots, T\}$

3. action sequence and state evolution restrictions

4. initial state x_0

Uncertainty

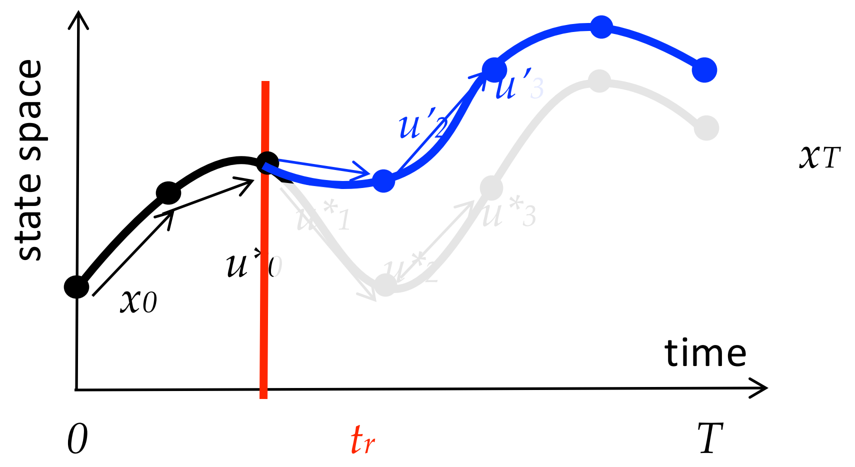
- Microgrid operation is impacted by factors that are not easily predictable
  - the weather, which impacts renewable generation and consumption
  - outages of steerable generation or storage
- Some events may thus turn the open-loop sequence u^* suboptimal or infeasible
- This can be mitigated by the a receding horizon approach

Receding horizon approach

Example: demand variation or restriction on x or u are observed at time t_r

Receding horizon approach: update the sequence of control actions

1. Re-estimate the parameters (demand, availabilities)
2. Re-solve the open-loop formulation



So, finally, when are decisions applied?

- Every time we solve the optimization problem above, we "freeze" some decisions:
  - not only the decisions occurring before the next re-optimization
  - but also decisions that have a high impact on the interactions within the microgrid or with the public grid, and that span the whole decision horizon
- Hence, depending on the moment of the day, some decisions may or not be re-optimized

Decisions, in practice

- Storage devices: Set point for charging / discharging
- Steerable generation
- Non-steerable renewable generation: curtailment
- Load shedding
- Load flexibility
- Power electronics

Remark: decisions we do not consider

We do not consider **investment decisions**

- This is the topic of another topic on sizing

We do not consider **maintenance decisions**

- Maintenance cost can be accounted for in sizing
- In operation, scheduled maintenance are just extra constraints or data updates (e.g. PV is out)
- If necessary, maintenance scheduling could be stated as an extension of operational planning

Constraints, in practice

- Capacity of devices
- Inverters constraints
- Demand-side management
- Generation management
- Regularization:
  - avoid changing decisions if unnecessary/undesirable

Optimization objectives

The invoice

- (In Belgium), the invoice of a user connected to a distribution network is composed of:
  - A part proportional to the energy consumed
  - A part proportional to the capacity of the connection, i.e. the amount of power the user can withdraw from the distribution grid
  - A part proportional to the "cos phi"
  - Taxes and other contributions
- This varies a lot as a function of the type of connection (i.e. of the voltage level and overall consumption)

Minimize the energy purchase cost

- The microgrid is subject to a dynamic price signal. At every time t, it can buy electricity at a price p_t
- Then, it will try to
  - consume & charge the storage devices during low price periods
  - produce & discharge the storage devices during high price periods
- Note: for now, we consider that
  - the microgrid cannot influence the price
  - there is no imbalance penalty
  - on the other hand, we will not always assume the price is known in advance.

Maximize the electricity sale price

- In a similar way, the price at which a retailer will buy back the energy can be described as a vector of prices, one per hour of the day.
- At a time t, the sale price is obviously always lower than the purchase price:
  - because the retailer takes a margin
  - because the purchase price includes the grid fees, taxes, etc.
- There may be an injection fee depending on the DSO

Minimize the peak

- A grid user pays a monthly fee function of his peak quarter-hourly consumption over the last 12 months.

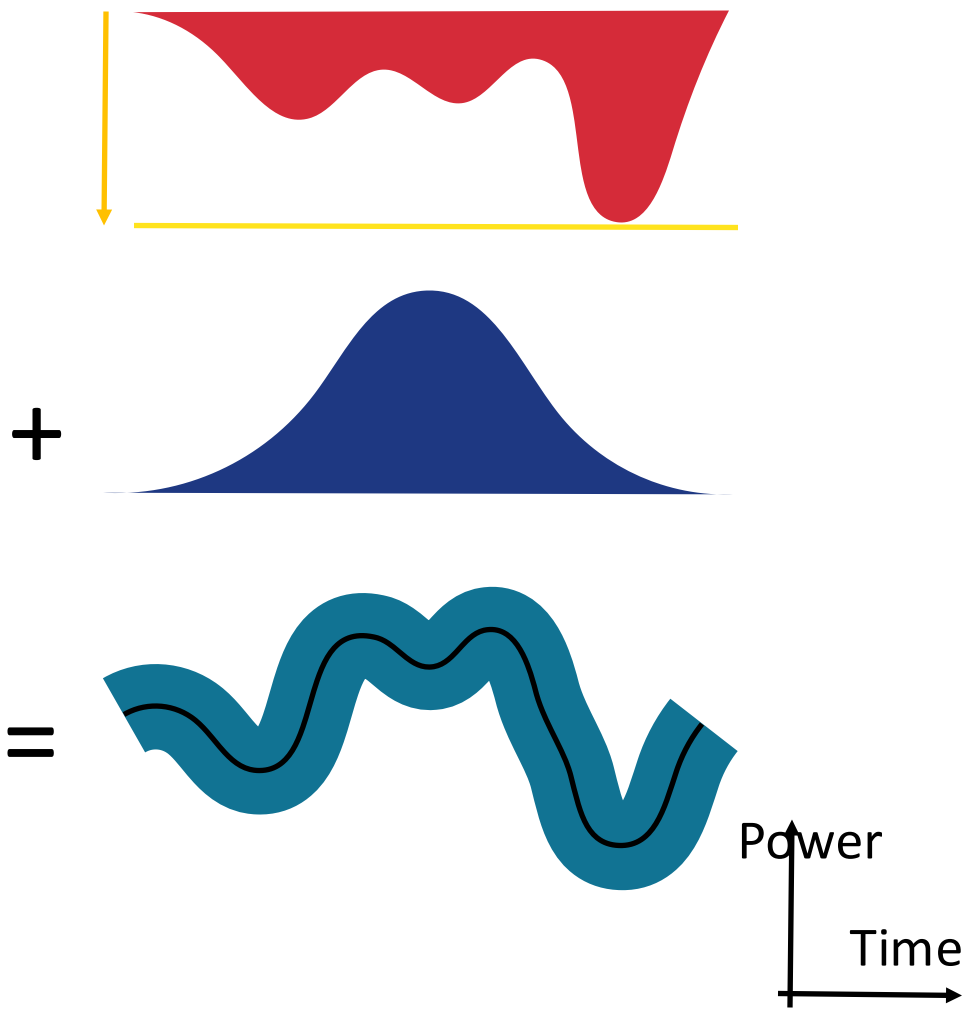
- Remark: this introduces a huge time coupling in the operation problem.

Maximize the reserve

- Keeping some reserve, i.e. some flexibility to quickly change the net position (total generation - total consumption) of the microgrid is important for two reasons:
  - It can be used to sell ancillary services to the grid
  - It can be used to stabilize the microgrid, in islanded mode.

In summary

- Costs
  - Energy consumption
  - Peak penalty
- Revenues
  - Energy production
  - Ancillary services



Minimize components' degradation

- Generation devices, such as internal combustion machines, have a lifetime which varies significantly with the way they are used.
- Batteries suffer of the same problem. However, this depends a lot with the type of battery technology.

(Islanded mode) Ensure security of supply

In case of public grid service interruption, the objective of the microgrid may suddenly switch to simply keeping the critical loads powered as long as possible.

All these objectives are (most of the time) conflictual

- For instance:
  - Minimizing the peak can lead to opportunity losses with respect to low energy purchase prices
  - Maintaining a level of reserve can lead to peak increases and also to some opportunity losses with respect to energy purchase/sale price
  - Minimizing component degradation should be put in perspective with the opportunity losses it generates
- Hence we must **reach a tradeoff between these objectives**

Load models for demand-side management

What are the electrical devices in your house?

On the demand side

- Lights
- Fridges
- TV, computer, etc.
- Dishwasher
- Washing machine
- Tumble dryer
- Electrical vehicle
- Hot water boiler
- Heat pump
- Direct heating
- Pumps
- etc.

On the generation side: PV, ...

+ storage

How can you characterize these loads?

- Power rating (kW, kVA, kvar)
- Power consumption pattern
- Energy consumption
- Efficiency
- Flexibility
- Controllability
- Behavior w.r.t. voltage variation, frequency variation

The next models are inspired from

- Roh, H. T., & Lee, J. W. (2015). Residential demand response scheduling with multiclass appliances in the smart grid. IEEE Transactions on Smart Grid, 7(1), 94-104.

Loads can be subdivided in 5 categories

- **E**lastic / **I**nelastic
- **M**emory**L**ess, with **F**ull **M**emory or **P**artial **M**emory
- Interruptible or **U**n**I**nterruptible

Set	Appliances
$\boldsymbol{A}_{EML}$	light bulbs with controllable brightness, electric fans with controllable speeds
$\boldsymbol{A}_{EFM}$	battery chargers (electric vehicles) with controllable charging rates
$\boldsymbol{A}_{EPM}$	electric heaters, air conditioners, refrigerators
$\boldsymbol{A}_{IEI}$	battery chargers (electric vehicles) with fixed charging rates, computers with int
$\boldsymbol{A}_{IEUI}$	washing machines, dishwashers, electric ovens, televisions, light bulbs without

A model is proposed for each category

- Let x_a^t be the consumption of appliance a at time t
- Let y_a^t be an integer variable that denotes whether appliance a starts at time t
- Parameters define limits on x_a^t (x_a^{min}, x_a^{max}), minimum performance thresholds of appliances' performance (R_a, R_a^t), energy consumption for inelastic ones (E_a), etc.

E.g. elastic with full memory loads (EFM)

Each appliance a also has the maximum and minimum values for its energy consumption, $x_a^{\max}$ and $x_a^{\min}$, respectively, at each sub-interval t, that is

$$x_a^{\min} \leq x_a^t \leq x_a^{\max}, \quad \forall t \in \boldsymbol{T}_a, \ \forall a \in \boldsymbol{A}_{\mathrm{EFM}}. \qquad (10)$$

Each appliance a has its utility function $U_a(\boldsymbol{x}_a)$, which is defined as

$$U_a(\boldsymbol{x}_a) = U_a\left(\sum_{t \in \boldsymbol{T}_a} x_a^t\right), \quad \forall a \in \boldsymbol{A}_{\mathrm{EFM}}. \qquad (11)$$

(...)

We also assume that the utility function is a concave function. In addition, we assume that for each appliance a, its user has the following requirement:

$$U_a(\boldsymbol{x}_a) \geq R_a, \quad \forall a \in \boldsymbol{A}_{\mathrm{EFM}}. \tag{12}$$

This requirement indicates that the performance of appliance a that depends on its total energy consumption should be higher than or equal to its minimum threshold R_a. We define the energy scheduling constraint of appliance $a \in \boldsymbol{A}_{\mathrm{EFM}}$ as

$$X_a = \left\{ \boldsymbol{x}_a \middle| \begin{array}{l} U_a\left(\sum_{t \in \boldsymbol{T}_a} x_a^t\right) \geq R_a, \quad \forall t \in \boldsymbol{T}_a \\ x_a^{\min} \leq x_a^t \leq x_a^{\max}, \end{array} \right\}, \quad \forall a \in \boldsymbol{A}_{\mathrm{EFM}}. \tag{13}$$

Overall problem

$$\begin{aligned}
\underset{\boldsymbol{x}}{\text{maximize}} \quad & \mathrm{NU}(\boldsymbol{x}) \\
\text{subject to} \quad & \sum_{a \in \boldsymbol{A}} x_a^t \leq E_{\text{th}}^t, \quad \forall t \in \boldsymbol{T} \\
& \sum_{t \in \boldsymbol{T}} \sum_{a \in \boldsymbol{A}} \lambda^t x_a^t \leq C_{\max} \\
& \boldsymbol{x}_a \in X_a, \quad \forall a \in \boldsymbol{A}.
\end{aligned} \tag{28}$$

$$\mathrm{NU}(\boldsymbol{x}) = \sum_{a \in \boldsymbol{A}_{\mathrm{EML}} \cup \boldsymbol{A}_{\mathrm{EFM}} \cup \boldsymbol{A}_{\mathrm{EPM}}} w_u U_a(\boldsymbol{x}_a) - w_c \sum_{a \in \boldsymbol{A}} \sum_{t \in \boldsymbol{T}} \lambda^t x_a^t \tag{27}$$

Results

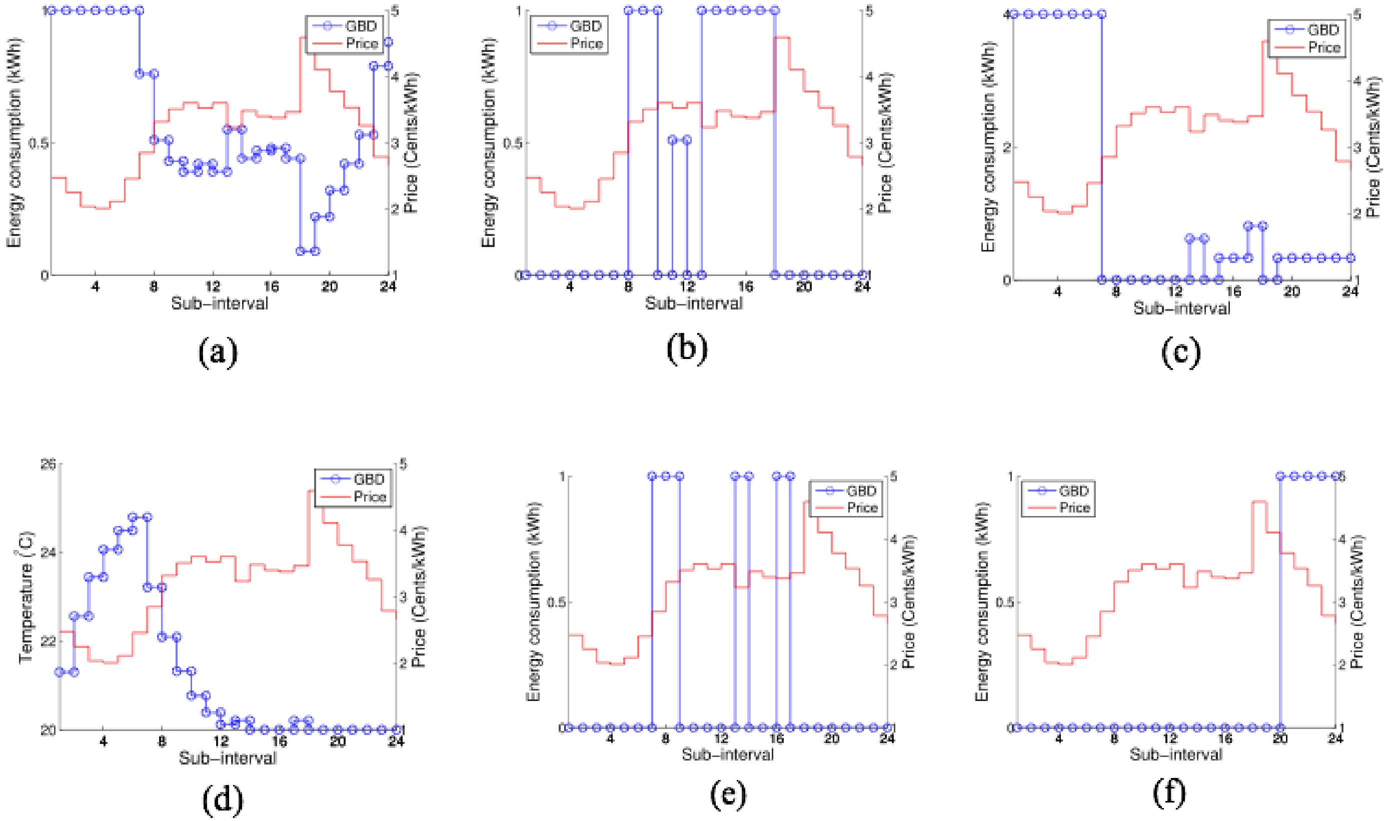


Fig. 2. ECS of the appliance in each set. Elastic appliance with a (a) memoryless property, (b) full memory property, and (c) partial memory property. (d) Temperature of elastic appliance with a partial memory property. Inelastic appliance with an (e) interruptible operation and (f) uninterruptible operation.