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Contribution to Multi-Energy Flow Management for Building Energy Hub

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Abstract

Global demand for primary fossil energy continues to increase. However, the production of energy from fossil fuels, in addition to depleting available reserves, releases millions of tons of Greenhouse Gas (GHG) into the atmosphere. Thus, it is obvious that the high concentration of GHGs in the air disrupts the natural greenhouse effect and consequently causes global warming. The implementation of action plans aimed at reducing greenhouse gas emissions has led all countries to use clean energy sources (sun, earth, wind) called renewable energies and also to rationalize the use of energies whether based on fossil fuels or renewable. Our paper presents a modeling of the demand and its management to ensure an optimization of the energy consumption and the reduction of its bill

Keywords: *Energy efficiency, energy hub, renewable energy, smart house, Energy storage, IoT.*

1. Introduction

As global demand for fossil primary energy increases, emissions from coal, gas and oil continue to climb. However, the production of energy from fossil fuels, in addition to depleting available reserves, emits millions of tons of greenhouse gases (GHG) into the atmosphere. Thus, it is obvious that the high concentration of GHGs in the air, disturbs the natural greenhouse effect and therefore causes global warming.

Indeed, fossil fuels (oil, gas and coal) come from rocks formed by the fossilization of buried plants and stored in the subsoil for several million years. Therefore, they are rich in carbon, which is released as CO_2 during their combustion.

Furthermore, the availability of reserves is a major source of concern. At the current rate of consumption, oil will be the first fossil fuel that we will have to do without. According to projections, there would remain between forty and sixty years of proven reserves of conventional oil. Natural gas could be exploited for another seventy years. For coal, there would be two centuries of reserves. Regarding nuclear energy, according to the IAEA and the World Nuclear Association, the current reserves of uranium are 30 years of operation of current reactors if the price is less than $ 40 per kg of uranium and more than 60 years consumption of the current fleet if the production cost rises to $ 80 per kg. However, by adding all the proven reserves (and not extracted today) we think that there are a little more than 200 years of consumption (depending on the price of uranium). It could be that we still have these energies a little longer because we base ourselves on the proven reserves, that is to say the reserves that we are sure to be able to exploit. However, estimates are made in order to know the ultimate reserves that could be discovered, thus increasing the duration of energy exploitation.
The implementation of action plans to reduce the emission of greenhouse gases has led all countries to use clean energy sources (sun, earth, wind) called renewable energy and also to rationalize the use of energy, whether based on fossil fuels or renewable.

2. Related works

All Much work has focused on enriching the functionalities of the electricity network to move from centralized and unidirectional management ranging from production to consumption, to distributed and bidirectional management to enable it to operate not only in supply, but also in collection, and also to adjust its contribution or its withdrawal according to the level of distributed production of renewable electricity. This constituting the heart of the reflections around future smart grids or “Smart Grids”. It is a question of instrumenting the electricity networks with information technologies to make them communicative[1][5]. The technological aspects of the smart grid have been widely studied. This is a comprehensive approach for optimizing the consumption of electrical energy

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by all users. In our study, we want to focus on the participation of a given user in the process of optimizing consumption. Fig. 1

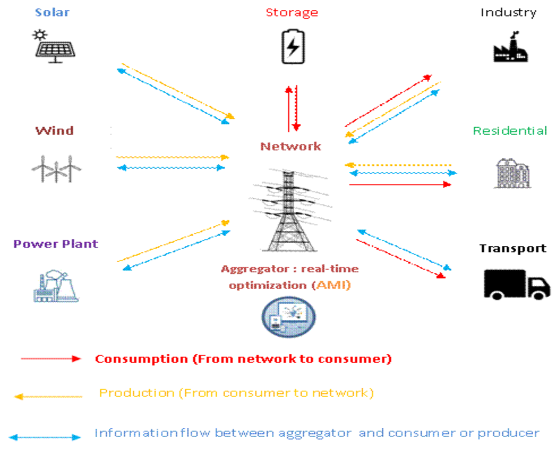

Fig. 1. Power and information flow in the "Smart Grid" environment

Energy in a building can either be in the form of a load (eg: household appliance, radiator) or in the form of a source (eg: battery, solar roof, micro-wind turbine). The problem of energy management in a building thus lies in the fact of using the sources as much as possible to meet the needs of the loads while reassuring the same level of comfort (Autonomous Building) [3][4]

2.1. Energy management system in the building

A building energy management system (BEMS) called also "Energy management and control system" is a set of equipment equipped with microcontrollers with communication capabilities via standard protocols, a centralized control system and a man-machine interface making it possible to perform certain functions for optimizing, controlling and monitoring energy consumption. Generally, these systems target commercial tertiary buildings to manage the consumption of heating, air conditioning, domestic hot water and lighting services. [11]

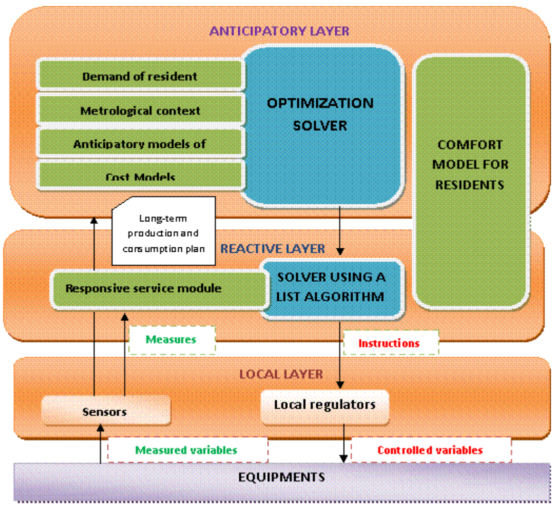

Fig. 2. Multi-layer control scheme for energy management in the home

2.2. Towards the optimization of energy flows in the home

The management of energy flows in the building can be assimilated to the management of physical flows in a production system of goods in which the problems of planning and scheduling are close. It can therefore be formulated as a planning problem with allocation of resources[6][7].

2.3. Overall characterization of the problem of managing energy flows

Optimization problems are usually characterized by an "objective function", which will be minimized or maximized until reaching an optimum.

2.3.1. Optimization criteria

The objective of optimized energy management in the building is to achieve the best possible configuration of the energy flows therein to best meet the following three criteria[2]:

- User comfort
- Investment and operating costs
- Reduction of pollution

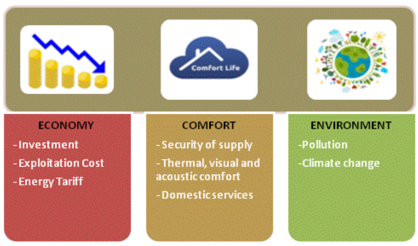

Fig. 3. Three criteria of Energy Control in the home

2.3.2. Optimization or decision variables

Optimization variables are a set of variables, often the level of a resource or activity, the optimal value of which will be determined by the optimization procedure. These variables are sometimes qualified as "decision variables", non-random and controllable and which represent the degrees of freedom on which one can play to achieve the best performance of the system within the meaning of the criterion sought.

2.3.3. Constraints

Constraints are the mathematical translation of the conditions that a solution to a optimization problem must satisfy. In principle, the constraints imposed on a problem of managing energy flows are typically:

- Constraints on the availability of energy resources
- Constraints of energy conservation and balance between energy production and consumption at the global level of the energy system.

2.3.4. Parameters

Parameters are quantities of known value which constitute the input data an optimization problem. Their value does not change during the optimization process and remains stable unlike the variables. the parameters are typically:

- Environmental parameters (e.g. temperature)

- The technical parameters which represent the specific features of the building's energy supply equipment (e.g. power, efficiency)
- The economic parameters which include the various costs (e.g. purchase price, energy resale price)

3. Modeling of multi-energy systems

3.1. "Energy Hub" modelling framework

The "energy hub" approach offers an open and easy modelling framework extensible with a relatively simple mathematical representation and at the same time able to describe any possible interaction and coupling between energy flows within multi-energy systems. There is a wide spectrum of real installations that can be designed as an "energy hub". These can range from the size of a single building to the network of production and distribution of a city or an entire country[8][9][10].

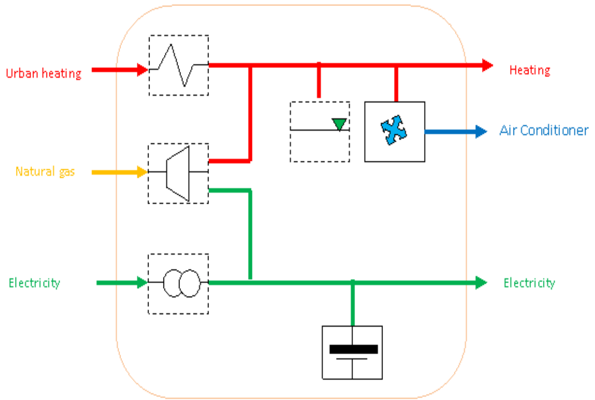

Fig. 4. Example of an "energy hub" with a transformer, a heat cogenerator/electricity, absorption chiller, heat exchanger, battery and hot water storage tank

3.2. Modeling convention

The modeling of the energy flow management problem will be carried out taking into account the assumptions and simplifications listed below:

- The flow of power through the energy conversion device is only influenced by the performance of the device and no other quantity.
- The energy converters have a constant conversion efficiency.
- The storage model is independent of physical phenomena (eg aging)
- Within the "energy hub", energy loss only occurs at the level of energy conversion and storage elements

We consider the set of energy vectors E whose members are denoted by small Greek letters:

$$\alpha, \beta \dots \omega \in \varepsilon = \{electric(e), gas(g), heat(h) \dots\} \quad (1)$$

An "energy hub" has a number of energy converters gathered in a set C:

$$C = \{1,2, \dots n_c\} \quad (2)$$

n_c indicates the total number of converters present in the energy hub. We identify the subset $C_\alpha \subseteq C$ encompassing all the elements that convert the energy vector α into other types of energy:

$$C_\alpha = \{1,2, ..n_{c\alpha}\} \quad (3)$$

An "energy hub" system is also equipped with energy storage units which are placed in a set S:

$$S = \{1,2, \dots n_S\} \quad (4)$$

Where $n_s$indicates the total number of storages present in the "energy hub". Of the same so that for the converters, the subset α ⊆ S gathers all the elements which store energy of nature α:

$$S_\alpha = \{1,2, \dots n_{S\alpha} \quad (5)$$

3.3. Energy supply

The energy required by an "energy hub" installation can be acquired as well from centralized resources connected to the distribution networks only from distributed and local sources such as renewable, generator sets, etc.

3.3.1. Energy distribution network

Energy distribution networks (in the broad sense and not just electricity) refer to all the infrastructure necessary to transport energy from production centers to consumption areas.

The power drawn P_α by the customer at any time "t" must never exceed the subscription power $\overline{P}_\alpha$ which he subscribes with his distributor:

$$0 \le P_\alpha(t) \le \overline{P_\alpha} \quad (6)$$

Same as the renewable electricity injected into the network can never go beyond a ceiling called $\overline{P}_\gamma^{inj}$ the penetration limit:

$$0 \le P_\gamma(t) \le \overline{P}_\gamma^{inj} \quad (7)$$

3.3.2. Distributed generation of renewable

3.3.2.1. Photovoltaic solar energy

The variations in temperature Δθ, current ΔI and voltage ΔV of the solar modules are calculated from the following set of equations:

$$\Delta\theta(t) = \theta_a(t) + \frac{R(t)}{800}(NOCT - \theta_{ref}) - \theta_{STC} \quad (8)$$

$$\Delta I(t) = \alpha_{sc}(\frac{R(t)}{R_{STC}})\Delta\theta(t) + \frac{R(t)}{R_{STC}} - 1)I_{SC}$$
(9)

$$\Delta V(t) = -\beta_{oc}\Delta\theta(t)) - r_s\Delta I(t)) \quad (9)$$

R Solar irradiation in W / m2
NOCT Normal temperature of use of the cell in ◦C
θ_c Outdoor air temperature in °C
θ_{ref} Reference ambient temperature specified at 20°C
θ_{STC} Temperature under standard test conditions

	specified at 25°C
I_{sc}	Short-circuit current
α_{sc}	Temperature coefficient of the short-circuit current
R_{STC}	Solar irradiation measured under standard test conditions equal to 1000W / m2
β_{OC}	Temperature coefficient of the open circuit current
r_s	Series resistance in the equivalent circuit

The continuous power supplied by each P_v module under a given weather condition can be obtained by the following formula:

$$Pmod\ (t) = \left(V_{oc} + \Delta V(t)\right)\left(I_{sc} + \Delta I(t)\right) \tag{10}$$

V_{oc} is the open circuit voltage (open circuit voltage). The total power delivered by an installation composed of n_p panels is therefore equal to:

$$P_{pv}\ (t) = P_{mod}(t).n_p \tag{11}$$

3.3.2.2. Wind power

Wind power involves drawing kinetic energy from the wind by means of a mounted propeller on a mast and coupled to an electric generator to produce direct current (DC) or alternative (AC). The level of electricity developed by a wind turbine is mainly a function wind speed and nominal power. According to Berthold et al. (2011), the power theoretically recoverable from a wind turbine can be determined by:

$$P_w = \frac{1}{2}\rho\ S\ V^3(t)C_p \tag{12}$$

ρ	Air density (approximately 1.23 kg / m^3 at 15°c)
S	Area swept by the blades in m²
v	Wind speed in m/s
Cp	Coefficient of performance

3.4. Energy conversion

In general, two forms of conversion can be distinguished:

• Simple conversion to move from one form of energy to another. A frequent example of this process is the transformation of the chemical energy of a fuel into heat in a boiler.

• The multi-physical conversion in which one form of incoming energy is transformed into several other different types of energy. The simultaneous production of electricity and heat in cogeneration plants is an emblematic example.

the operation of a basic energy conversion device which receives the energy vector α and delivers energy of type β with a certain efficiency $\eta_{\alpha\beta}$.

The correlation between the input power P_α^{in} and the output power P_β^{out} can be described by the following coupling relation:

$$P_\beta^{out} = P_\alpha^{in}\ \eta_{\alpha\beta}\{\forall\ \alpha, \beta \in \varepsilon \,|\, \alpha \# \beta\} \tag{13}$$

When the total contribution of an energy carrier is shared between several converters. The incoming energy flow P_α^{in} is distributed between $\eta_{\alpha\beta}$ converters. The so-called "distribution factor" $\Gamma_{\alpha,i}$ specifies how much of the total flux P_α^{in} flows in the converter i ϵ $C_\alpha = \{1, 2, \cdots, \eta_{\alpha\beta}\}$:

$$P_{\alpha,i}^{in} = P_\alpha^{in}\ \Gamma_{\alpha,i} \tag{14}$$

The law of conservation of energy at the junction of the input flow imposes both requirements following the distribution factors:

1. given that each branch carries just part of the total input flow, all distribution factors must verify:

$$0 \le \Gamma_{\alpha,i} \le 1 \quad \forall\ \alpha \in \varepsilon\ ,\forall\ i \in C_\alpha \tag{15}$$

2.the sum of the distribution factors associated with the same junction is equal to one:

$$\sum_{i\in C_\alpha} \Gamma_{\alpha,i} = 1 \tag{16}$$

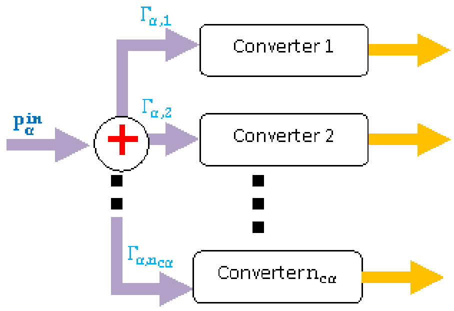

Fig. 5. Distribution of the total energy flow at the input junction of several converters

3.5. Energy storage

A storage system, whatever the nature of energy it may contain, is made up of an "interface" and an "internal storage" or "ideal". The storage interface can be modeled similar to a converter device. The power ratio between the two sides of the storage interface is given by:

$$\tilde{P}_\alpha^s = e_\alpha P_\alpha^s\ \forall\ \alpha \in \varepsilon \tag{17}$$

The term e_α indicates the manner in which the internal power $\check{P}_\alpha^s$ of a storage system containing energy of type α is affected by having actually exchanged the power $\check{P}_\alpha^s$ with the external medium. This factor is defined according to the direction of the power flow, i.e., depending on whether the storage is loaded or unloaded:

$$\begin{cases} \text{si } P_\alpha^s \geq 0 \text{ (charge)} & \text{alors } e_\alpha = \eta_\alpha \\ \text{si } P_\alpha^s < 0 \text{ (décharge)} & \text{alors } e_\alpha = \frac{1}{\eta_\alpha} \end{cases} \tag{18}$$

The residual charge inside the storage, in other words its SOC state of charge after a certain operating time T is equal to its initial content plus the integral over the power time:

$$SOC_\alpha\ (T) = SOC_0 + \int_0^T \tilde{P}_\alpha^s.dt \tag{19}$$

By discretizing the formula of the continuous state of charge over time periods of length Δ, the content of the storage at the end of each period t is calculable thanks to the equation:

$$SOC_\alpha\ (t) = SOC_\alpha\ (t-1) + \Delta\tilde{P}_\alpha^s.dt \tag{20}$$

3.6. Integrated energy hub model

Consider an energy unit where multiple input energies are converted to multiple output energies. This conversion can be done either by a single device or by a combination of devices with dedicated inputs and outputs. Gather all the input powers $\breve{P}_{\alpha}^{in}$, $\breve{P}_{\beta}^{in}$, · · ·, $\breve{P}_{w}^{in}$ in in a Pin vector and all the output powers $\breve{P}_{\beta}^{out}$, · · ·, $\breve{P}_{w}^{out}$ in a vector Pout, makes it possible to formulate the conversion model with multiple inputs and outputs covering all port-to-port couplings in analogy with formula (14) as follows:

$$\begin{bmatrix} P_{\alpha}^{out} \\ P_{\beta}^{out} \\ . \\ . \\ . \\ P_{w}^{out} \end{bmatrix} = \begin{bmatrix} \Gamma_{\alpha,i}\eta_{\alpha\alpha} & \Gamma_{\beta,i}\eta_{\beta\alpha} & \cdots & \Gamma_{w,i}\eta_{w\alpha} \\ \Gamma_{\alpha,i}\eta_{\alpha\alpha} & \Gamma_{\beta,i}\eta_{\beta\beta} & \cdots & \Gamma_{w,i}\eta_{w\beta} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ \Gamma_{\alpha,i}\eta_{\alpha w} & \Gamma_{\beta,i}\eta_{\beta w} & \cdots & \Gamma_{w,i}\eta_{ww} \end{bmatrix} \quad (21)$$

The matrix C is called the coupling matrix.

An "energy hub" system can also include a variety of storage units which can be located both upstream of the converters and downstream. In this case, the equation corresponding to the output power flow is as follows:

$$P_{\beta}^{out} = (P_{\alpha}^{in}\Gamma_{\alpha,i} - P_{\alpha}^{s})\eta_{\alpha\beta} - P_{\beta}^{s} \quad (22)$$

The above formula can be developed as follows:

$$P_{\beta}^{out} = P_{\alpha}^{in}\Gamma_{\alpha,i}\eta_{\alpha\beta} - P_{\alpha}^{s}\eta_{\alpha\beta} - P_{\beta}^{s} \quad (23)$$

All the influence of the storage operations can by superimposition be summarized in a only equivalent storage stream $P_{\beta}^{s,eq}$:

$$P_{\beta}^{out} = (P_{\alpha}^{in}\Gamma_{\alpha,i}\eta_{\alpha\beta}) - P_{\alpha}^{s,eq} \quad (24)$$

with $P_{\alpha}^{s,eq} = P_{\alpha}^{s}\eta_{\alpha\beta} + P_{\beta}^{s}$

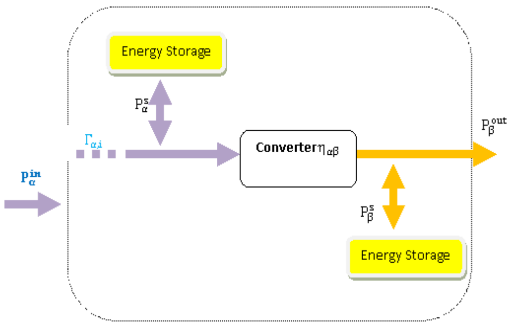

Fig. 6. Influence of the storage flow on the input and output power of "energy hub"

By adding the vector of equivalent storage streams $P^{s,eq}$ to the matrix notation (22), the complete model of an energy hub composed of n_c conversion devices and ns storage takes the following form:

$$P^{out} = CP^{in} - P^{s,eq} \quad (25)$$

4. Formulation of the optimal management problem

4.1. Elements taken into account in the optimization model

For the overall formulation of the energy flow optimization problem (EFOP), the elements below will be taken into account:

- Self-consumption subsidy
- Dynamic electricity tariff
- Inelasticity of household loads

4.2. Formulation of the optimization problem

The overall formulation of the energy flow optimization problem is given for a planning horizon H divided into n time periods t of length Δ under constraints of energy availability.

4.2.1. Objective function

For the formulation of the objective function, the energy flows below will be considered:

- Photovoltaic panels

The quantity of electricity locally consumed by the producer is given by:

$$P_{pv}^{c} = P_{pv}(1 - \Gamma_{pv})\eta^{inv} \quad (26)$$

The quantity of energy sold to the supplier is equal to:

$$P_{pv}^{v} = P_{pv}\Gamma_{pv}\eta^{inv} \quad (27)$$

- Boiler

The thermal power generated by the boiler:

$$P_{cg}^{c} = P_{g}(1 - \Gamma_{g})\eta^{cg} \quad (28)$$

- CHP "Combined Heat and Power" micro gas co-generator

The heat and electricity produced by the CHP system are calculated from the following equations:

$$P_{e}^{CHP} = P_{g}\Gamma_{g}\eta_{ge}^{CHP} \quad (29)$$

$$P_{h}^{v} = P_{g}\Gamma_{g}\eta_{gh}^{CHP} \quad (30)$$

The cost minimization criterion can therefore be formalized by the following function:

$$P_{pv}^{c} = P_{pv}(1 - \Gamma_{pv})\eta^{inv} \quad (31)$$

λ_e Represents the electricity purchase tariff
λ_g represents the gas purchase price
λ_{pv}^{v} represents the PV resale price
λ_{pv}^{c} represents the PV self-consumption bonus

4.2.2. Constraint related to the flow of photovoltaic energy

The table below presents the constraint related to the flow of photovoltaic energy:

The term Ψ represents the purchase of electricity from the supplier such that $\Psi = 1 \rightarrow P_e \geq 0$. Depending on the different values of Ψ(t) and $\Gamma_{pv}(t)$, which managed the distribution of the P_v flow between the house and the grid, the different situations of buying and selling electricity can theoretically take place.

Table 1. Constraint related to the flow of photovoltaic energy

	Ψ = 0	Ψ = 1
$\Gamma_{pv} = 0$	No resale No purchase	No resale Purchase of the complement to the network
$\Gamma_{pv} > 0$	Resale of surplus PV No purchase from the network	Resale of PV Buying from the network

4.2.3. Energy flow balance constraints

Equations (33) and (34) are written to ensure the balance between the production and consumption of electricity and heat, respectively:

$$L_e(t) = P_{pv}(t)\eta^{inv}(t) - P_{pv}(t)\eta^{inv}\Gamma_{pv}(t)\left(1 - \Psi(t)\right) + P_e(t)\Psi(t) + P_g(t)\Gamma_g(t))\eta_{ge}^{CHP} - P_e^s(t) \quad (33)$$

$$L_h(t) = P_g(t)\Gamma_g(t)\eta_{ge}^{CHP} + P_g(t)\left(1 - \Gamma_g(t)\right)\eta^{CG} - P_h^s(t) \quad (32)$$

$$\Gamma_{pv}(t) + \Psi(t) \leq 1 \quad (33)$$

The overall energy production and consumption represented by the two equations above can also be modelled in the energy hub. The following equations that reflect the state of charge of the storage media. They are essential to know the available reserve of energy at each moment:

$$SOC_e(t) = SOC_e(t-1) + \tilde{P}_e^s(t) - E_{ve}(t) \quad (34)$$

$$SOC_h(t) = SOC_h(t-1) + \tilde{P}_h^s(t) \quad (35)$$

4.2.4. Energy availability constraints

The power flows entering an energy hub as well as the individual power input of each of its components (converters and storage) are limited.
This is modeled by inequalities (38) to (47):

$$\varsigma(t)P_e^{d,max} \leq P_e^s(t) \leq \varsigma(t)P_e^{c,max} \quad (36)$$

$$P_h^{d,max} \leq P_h^s(t) \leq P_h^{c,max} \quad (37)$$

$$\underline{soc}_e \leq SOC_e(t) \leq \overline{SOC}_e \quad (38)$$

$$0 \leq SOC_h(t) \leq C_h \quad (39)$$

$$0 \leq P_e(t) \leq \overline{P}_e \quad (40)$$

$$0 \leq P_e(t) \leq \overline{P}_g \quad (41)$$

$$0 \leq \left(1 - \Gamma_{pv}\right)P_{pv} \leq \overline{P}_{pv}^{inj} \quad (44)$$

$$\Gamma_g(t)P_g(t) \leq \overline{P}^{CG} \quad (42)$$

$$(1 - \Gamma_g(t))P_g(t) \leq \overline{P}^{CHP} \quad (43)$$

$$0 \leq \Gamma_{pv}(t) \leq 1 \quad (44)$$

4.2.5. Constraints related to storage equipment

The performance values of the storage interface can be connected to each other by:

$$\tilde{P}_\alpha^s = e_\alpha P_\alpha^s \quad \forall \alpha \in \varepsilon \quad (45)$$

The value of e_α depends on the direction of the power flow and can be managed by the "if-then" decision making functions:

$$\begin{cases} \text{si } P_\alpha^s \geq 0 \text{ (chargement de stockage)} & \text{alors } e_\alpha = \eta_\alpha \\ \text{si } P_\alpha^s < 0 \text{ (déchargement de stockage)} & \text{alors } e_\alpha = \frac{1}{\eta_\alpha} \end{cases} \quad (46)$$

So, we'll write for the electrical heat storage system:

$$\begin{cases} \text{si } 0 \leq P_h^s \leq P_\alpha^{c,max} \text{ (chargement)} & \text{alors } \tilde{P}_h^s = P_h^s\eta_h \\ \text{si } P_\alpha^{d,max} \leq P_h^s < 0 \text{(déchargement de stockage)} & \text{alors } \tilde{P}_h^s = \frac{P_h^s}{\eta_h} \end{cases} \quad (47)$$

Logical conditions will be processed by means of transformations. Same for the electrical storage system:

$$\begin{cases} \text{si } 0 \leq P_e^s \leq P_e^{c,max} \text{ (chargement)} & \text{alors } \tilde{P}_e^s = P_e^s\eta_b \\ \text{si } P_e^{d,max} \leq P_e^s < 0 \text{(déchargement de stockage)} & \text{alors } \tilde{P}_e^s = \frac{P_e^s}{\eta_b} \end{cases} \quad (48)$$

4.3. Transformation of logical conditions

The logical statement χ representing any clause cannot have for value of truth as true or false. Bemporad and Morari (1999) explain that such a proposition can be associated with a logical variable $\delta \in \{0, 1\}$ such that $\delta = 1$ if and only if χ is true, and 0 otherwise. They then take the example where χ implies the condition $f(x) \leq 0$ where f: $R^n \rightarrow R$ is linear, assuming that the continuous variable $x \in dom(x)$ is bounded by:

$$m \triangleq \min_{x \in dom(x)} f(x) \quad (49)$$

$$M \triangleq \max f(x) \quad (50)$$

The logical condition is then written $[\delta = 1] \leftrightarrow [f(x) \leq 0]$. As a consequence, we will have:

$$m \leq f(x) \leq 0 \leftrightarrow \delta = 1 \quad (51)$$

$$0 < f(x) \leq M \leftrightarrow \delta = 0 \quad (52)$$

We show that to translate this logical condition, one can use the mixed linear inequalities:

$$\{[f(x) \leq 0] \leftrightarrow [\delta = 1]\} \Leftrightarrow \begin{cases} f(x) \leq M(1 - \delta) \\ f(x) \geq \epsilon + (m - \epsilon)\delta \end{cases} \quad (53)$$

where ϵ is a very low value (typically the accuracy of the machine), above in which duress is considered to have been violated.
These new constraints will replace some constraints in the initial model. To finalize the transformation procedure, we link the value of $\tilde{P}_h^t(t)$ to that of $P_h^t(t)$ and the value of $\tilde{P}_e^s(t)$ to that of $P_e^s(t)$ through the binary variables defined in the previous step:

$$\tilde{P}_h^s(t) = \delta_h(t)(P_h^s(t)\eta_h) + (1 - \delta_h(t))\left(\frac{P_h^s(t)}{\eta_h}\right) \quad (54)$$

$$\tilde{P}_e^s(t) = \delta_e(t)(P_e^s(t)\eta_b) + (1 - \delta_e(t))\left(\frac{P_e^s(t)}{\eta_b}\right) \quad (55)$$

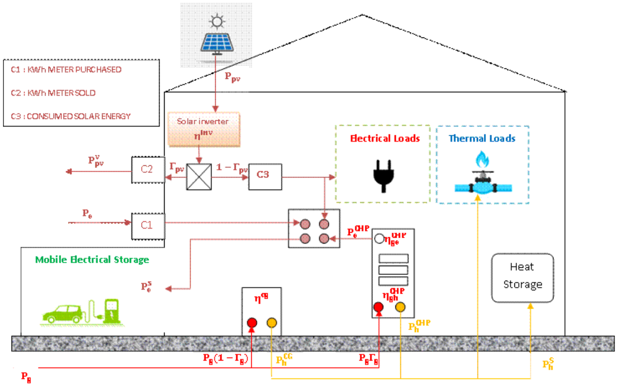

Fig.7. "Energy hub" representation of the power supply circuit of the building studied

5. Electric demand management

5.1. Demand and Peak Load Management

Demand-Side Management (DSM), or Demand Response (DR), is an essential part of the emerging smart grid paradigm. It is part of Energy Management Solutions (EMS), which also includes energy efficiency solutions.
Smart grids allow the disconnection of non-essential electrical appliances during high electricity demand, in order to limit the risk of major peaks in electricity consumption. These grids are still at the experimental stage, but this functionality is similar to that which can be achieved by a local load-shedding device to limit the subscription.
The technology is advancing, the electricity network is becoming more and more efficient, but some improvements depend on changes in consumer behavior and habits.

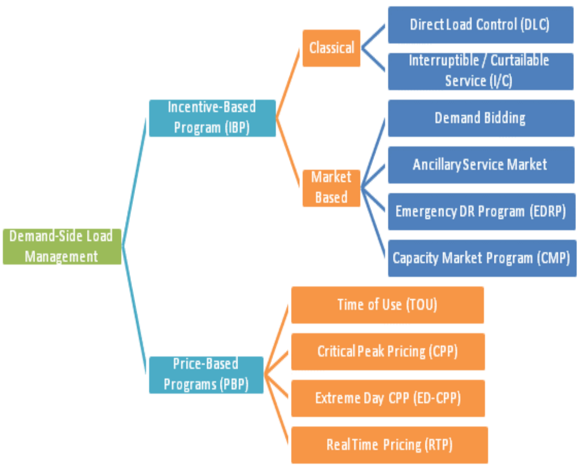

Fig. 8. Classification of DSM programs according to the US Department of Energy

5.2. Conventional Approaches to Electric Demand Management

Electricity generators and distributors typically use two approaches to managing electricity demand:

5.2.1. Direct load control

DLC " Direct Load Control " is the possibility to control the customer's electrical load by the supplier to reduce consumption peaks.

5.2.2. Local management through profit-sharing

The idea is to set up a dynamic tariff structure which, instead of encouraging consumption, would make customers pay a higher price for peak electricity. Customers would thus become players in their consumption and can take advantage of this to plan economical energy use.

5.2.3. Commercial programs

Trade programs can be classified according to the report to the U.S. Congress (DOE, 2006) into two broad categories:
- Incentive-Based Programs (IBP):

Customers enrolled in the IBP programs are rewarded with a credit, a discount on the invoice or financial rewards depending on the size of their contribution. In certain variants such as "interruptible" services and "capacity market», customers undertake to reduce their peak period expense by a predefined amount during the following periods and could face sanctions if they fail to do so.
- Price Based Programs (PBPs):

PBP programs are a group of local cost control methods that use dynamic price signals as a means of controlling customer consumption. In the most basic form, they apply TOU (Time Of Use) tariffs distinguishing between off-peak, normal and peak periods.

5.3. Electricity Demand Management in the Residential Sector

Demand management in the residential sector is beginning to attract increasing international interest. Various research studies have been carried out to analyze its various aspects. One very important aspect refers to the study of the needs and behaviors of occupants, which are very diverse, even among members of the same household. The latter have a strong influence on electricity consumption in the home because they are the ones who decide how and when the equipment works.

5.4. Local Demand Management at the Dwelling Level

Local demand management at the dwelling level can be done at the company level. of electricity by remotely controlling electrical loads. It can be done possibly at the level of private individuals by:
- On-site generation: local production of the emergency generator type to cover part of its peak demand.
- Electricity storage: The storage can be either for fixed use, it is then designated as stationary, or be mobile, in which case it is then qualified as an on-board vehicle (means transport, electronic devices, etc.).
- Control of household loads: This concerns the operation of electronic appliances. However, each appliance has its own type of use, its priority and its own consumption characteristics.

Depending on these particularities, the services provided by different equipment can be more at least flexible from a consumption point of view or even completely non-flexible.

5.5. Flexibility of services in residential housing

There are two different families of service to the inhabitant:

- Temporary services characterized by a limited consumption period, such as washing, cooking, lighting, etc. As shown in Figure 9, they account for a significant portion of electrical use in the dwelling.
- Permanent services are defined as services to the inhabitant that are consumed over any given period of time, usually one day. Examples include refrigeration, heating and air-conditioning services.

The result of this classification is a difference in capacity to be controlled and a difference in impact on the comfort of service users. There are inhabitant services that are considered "flexible" and can be influenced in several ways. They can be time-shifted and/or modulated during operation, for example by changing the parameters of a heating or air-conditioning thermostat. In the most radical cases, this modulation can go as far as complete load shedding of the service.

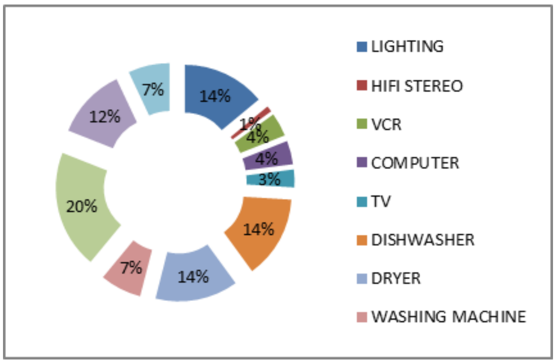

Fig. 9. Distribution of residential consumption by type of activity (ADEME France 2018)

5.6. Characteristics of the building system electrical demand management problem

The characteristics of the electrical demand management problem for building systems will be based on an electrical load management mechanism that relies on the shifting nature of the services provided by certain equipment in order to adjust the consumption curve of the house according to the price of electricity.

Shiftable services can be treated as tasks to be scheduled overtime and can be planned by a building energy management system. Optimization will eventually allow calculating the best launch dates for these services within a window of time set according to the preferences of the occupants and taking into account the availability of resources and the price of energy.

6. Conclusion

The "energy hub" approach presents a powerful tool for the integrated analysis of the production, storage, conversion and consumption of energy flows of different nature within new multi-energy systems. The practical interest of this approach lies in a simple and accessible mathematical representation.

The original formulation of the problem being non-linear of the PNLNE (Programming Non-Linear Integer Number) type, mathematical transformation tools were presented and applied in order to linearize the problem and allow its exact resolution.

The NNLP optimization model manages the consumption of services with a shifting nature, individuals can locally control their own electricity use during peak periods when the generating plants emit more greenhouse gases and the price is higher.

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