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Cédric Clastres, T.T. Ha Pham, F. Wurtz, S. Bacha. Optimal household energy management and participation in ancillary services with PV production. 2008. halshs-00323576v1

**HAL Id: halshs-00323576**

**<https://shs.hal.science/halshs-00323576v1>**

Submitted on 22 Sep 2008 (v1), last revised 8 Sep 2009 (v2)

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LABORATOIRE D'ECONOMIE DE LA PRODUCTION  
ET DE L'INTEGRATION INTERNATIONALE

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## **CAHIER DE RECHERCHE**

**N° 10**

### **Optimal household energy management and participation in ancillary services with PV production**

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# Optimal household energy management and participation in ancillary services with PV production

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July 2008

## Abstract

The work presented in this paper deals with a project aiming to increase the value of photovoltaic (PV) solar production for residential application. To contribute to the development of the new functionalities for such system and the efficient control system to optimize its operation, this paper defines the possibility for the proposed system to participate to the ancillary services, particularly in active power service provider. This service of PV-based system for housing application, as it does not exist today, has led to a market design proposition in the distribution system. The mathematical model for calculating the optimal operation of system (sources, load, and the exchange power with the grid) results in a linear mix integer optimization problem where the objective is to maximize the profit obtained by participating to electricity market. The approach is illustrated in an example study case. The PV producer could benefit from its intervention on balancing market or ancillary services market despite of the impact on the profit of several kinds of uncertainty, as the intermittence of PV source.

*Keywords* : energy management, ancillary services, PV production, household application

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## NOMENCLATURE

### *Model Parameters*

$\tau$	Ambient temperature [ $^{\circ}\text{C}$ ]
$\eta_B$	Storage efficiency
$c_g(t)$	grid electricity price (c€/kWh)
$c_{pen}(t)$	Penalty cost (c€/kWh)
$c_s(t)$	Price for purchasing PV production to network (c€/kWh)
$G$	Available radiation [ $\text{W}/\text{m}^2$ ]
$P_{gn}$	Contractual grid power limit [kW]
$P_{PVc}$	Peak power of PV generator [kWp]
$r_{ch}$	Charge rate [kWh/h]
$r_{dch}$	Discharge rate [kWh/h]
$S_{max}$	Storage system capacity [kWh]
$SOC_{max}$	Storage upper capacity limit [kWh]
$SOC_{min}$	Storage lower capacity limit [kWh]
$T$	Calculation step time [hour]

### *Decision variables*

$\alpha(t)$	Decision binary variable, $\alpha(t) = 1$ if the battery is in the charging mode, $\alpha(t) = 0$ if the battery in the discharging mode
$\beta(t)$	Decision binary variable, $\beta(t) = 1$ if the system imports grid energy, $\beta(t) = 0$ if the system purchases its PV production
$\alpha(t)$	Decision variable, used to translate the absolute relation into linear representation
$P_{bin}(t)$	Charge power consign [kW]
$P_{bout}(t)$	Disharge power consign [kW]
$P_g(t)$	Consumed grid power [kW]
$P_L(t)$	Electrical demand prevision [kW]
$P_{LP}(t)$	Consumed power by controllable loads
$P_{NLP}(t)$	Consumed power by non-controllable loads
$P_{PV}(t)$	PV available power [kW]
$P_s(t)$	PV power to be used locally [kW]
$SOC(t)$	Temporal state of charge [kWh]
$z(t)$	PV power to be injected to network [kW]

## 1. INTRODUCTION

During the last years, the residence sector is often placed as the biggest consumer of electricity. It represents also an important producer of greenhouse gases emissions. The problematic of energy management in building constitutes actually an essential interest point. Both the demand and supply side management in building has been studied world wide. At demand side, it is expected that consumed energy would be saved considerably by switching more intelligently the consumption [1], [2]. At supply side, the connected-grid PV system is usually proposed to residential user [3], [4]. Guided by many supported programs to develop the use of renewable energies such as investment subsidies, feed-in tariffs, green certificates [5] etc., the attention is particularly made in maximizing the PV production to inject to the network.

However, as progress in technology over the last decades leads to drop considerably PV module cost [6] and expand the use of PV solutions, the actual tendencies to develop the use of PV energy would evolve. Incentives policies would be reviewed to be reduced or replaced by others systems less costly or in accordance with market ([7], [8]). For example, we assist today to the introduction of market component in some incentives policies, as Spanish experiences [9], [10]. Moreover, projecting the medium future when the insertion of PV production becomes more significant [11], distribution networks could not tolerate the large fluctuations, and more constraints would be introduced: restrained injection power to network possibilities, higher requirements on providing service quality (current and voltage profile) or participation to ancillary services, etc. It means that, in order to exchange energy with the network, PV producer would be considered as any other independent power producer (IPP) with similar obligations. It means that the system, instead of considering its own objectives, must plan and coordinate its activities with the Distribution System Operator (DSO).

These issues ask for investigating the innovative energy architecture for housing applications. It is expected that the building of tomorrow should no longer be a passive element but a *positive, green* and *intelligent* element.

The project sustaining this paper, MULTISOL, has the ambition to design an economical and technical efficient framework for household energy management. A new architecture is proposed with: a PV based multi-sources system at supply side, and an optimal supply and demand side co-management. To contribute to the development of the new functionalities for such system and the efficient control system to optimize its operation, this paper defines the possibility for the proposed system to participate to the ancillary services, in particularly the active power service provider. Today, ancillary services market does not exist at distribution level (as in France for example). The DSO insures all these services and distribution tariffs paid them. But, as new renewable energy producers do not participate to the satisfaction of these services, they could not have incentives to consider in their strategy the impact on distribution activity they have.

This service of PV-based system for housing application, as it does not exist today, has led to a market design proposition in the distribution system. The mathematical model for calculating the optimal operation of system (sources, load, and the exchange power with the grid) results in a linear mix integer optimization problem where the objective is to maximize the profit obtained by participating to electricity market. In this paper, we investigate the benefit a PV producer could have to participate to ancillary services or balancing mechanisms. We will see that, with the use of an optimization system in production and consumption, the PV producer could benefit from its intervention on balancing market or ancillary services market. The intermittence lesson this conclusion but these incentives always exist and depends on penalty costs levels. The

approach is illustrated in an example study case. The impact on the profit of several kinds of uncertainty, as the intermittence of PV source, and the consumer behavior are analyzed.

## 2. MARKET DESIGN

Look at the development of electricity market, it is possible to see that the active power market exists for balancing the transmission system. The basic concept is that TSO imposes to energy producers to make power bids to balancing the system and insure some ancillary services. These bids are made on a day-ahead bases (day D-1 for hours in day D) or on an “hour-ahead” basis (for example, hour H-1 for deliver in hour H). They are paid at the marginal price that balances the system or at nodal prices (zonal marginal prices) if nodal areas exist. If producers cannot meet their bids, they incur imbalance costs computed on balancing marginal prices. So they could be remunerated or penalized for their bids, according to their position in production.

It is supposed that the electricity market developed in distribution network reproduces the behavior of balancing market in the transmission network. PV-based system with other producers is asked for providing power to insure the equilibrium and safety of local distribution network. They must offer a day-ahead active power bid, for the next 24-hours or hours before the balancing time. With this bid, they could insure some ancillary services. The remuneration of these services is made at zonal marginal price. In this paper, we evaluate these prices by the market or the balancing market prices. Thus, zonal prices depending of distribution zones could be introduced. This cut-out could lead to the existence of Zonal Marginal Prices (ZMP) for balancing the distribution network. The PV generation is intermittent and knows a lot of disturbances. So, it should have a gap between expected and real injected production. The expected power for the next day could differ from the real power injected in the distribution network. Then, the PV producer is penalized because it could not supply the offer of power it has made before. The penalty cost is computed referring to zonal market price and balancing tendency (see Table 1).

	Upward balancing tendency	Downward balancing tendency	Nil balancing tendency
Positive gap (expected power < real power)	PV producer receives ZMP <sup>2</sup>	PV producer pays ZMP	PV producer pays ZMP
Negative gap (expected power > real power)	PV producer pays ZMP	PV producer receives ZMP	PV producer pays ZMP

Table.1 : Costs and balancing tendencies

Beside the bid of active power, all producers would be called for making reactive power offers. This could be a standard obligation rate or with the existence of a market for reactive power. Controlled by inverter, the PV-based system can produce the reactive power [12]. The trade-off between active and reactive power depends on the standard rate or on their prices.

In this paper, we assume that DSO applies an obligation for reactive power provider. The intuition will be that the PV producer would bind its reactive power constraint and optimize its profit with active power bids or PV power consumption.

<sup>2</sup> In each case, rather than paying or receiving ZMP, the PV producer could pay or receive weighted average prices of upward or downward balancing tendency. As in the TSO balancing system, these prices could be put up or cut by a factor value.

The reactive power rate leads to reduce the value of active power bid on day ahead balancing market. If this standard is too high, then a tariff for reactive power could be necessary to compensate increases in cost of reactive power supply and diminutions in profit as active power consumed decreases. Losses could be both on consumed electricity (as the constraint on reactive power is high, the PV producer could consume less PV electricity) and on active power sold on the market of ancillary services or balancing day-ahead markets (as less active power could be sold on this market).

Anyway, as the reactive power produced by the system is based on the local production (a certain percentage of injection power) so it does not modify the way the optimization problem is formulated. So without loss of generality, in the following, we assume that this rate is zero.

### 3. DESCRIPTION OF MODEL FRAMEWORK

#### 3.1. System architecture

The proposed PV based multi-sources system with energy management for building application is given in Fig. 1 [4], [13].

A separation is made between production and consumption sides with supervision - control board for each. Production means (PV generator, network, battery storage system and others complementary sources) are connected to "Power production control board" to supply loads via the traditional electric delivery box called "Power delivery control board". A coupling and multi-sources management module integrated in the production board may permit the optimal control of the various power-flows. A demand side management module would rather be placed in the electric delivery box in order to facilitate the control - command of loads. Besides, power electronics interfaces are placed in the scheme as fluxes control actuators. Measurement and telecommunication equipments are also indispensable. The "Expert and Predictive System" is the core intelligent which receives information (weather forecast, electricity market, measurements, user characteristics and preferences ...), calculates the optimal strategy control and sends command order to equipments, etc.

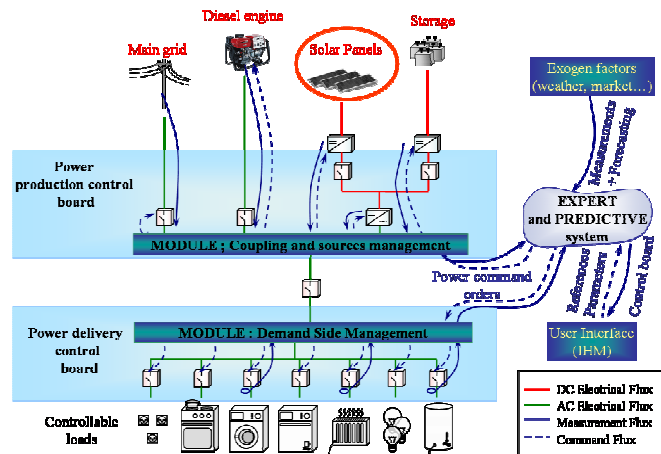


Fig. 1. Muti-sources system and sources and loads co-management system architecture

#### 3.2. Impact of intermittence characteristics

The PV producer knows two kinds of uncertainties.



The first one consists in PV production capacity which is calculated from the forecasting of radiation and temperature on site. As it can be seen in the Fig. 2 and 3, the uncertainty value is relatively high. Fig.2 reports an example of the temperature at a specific day (July, 5-th) during 10 years (from 1998 - 2007), [14] that shows the deviation could be more than  $\pm 5^{\circ}\text{C}$ . The uncertainty on expected solar radiation, as shown in the example on a reference day in the Fig. 3 [15], could induce a mean variation up to 40% of the predicted value. As the results, it is difficult for PV producers to anticipate exactly its production and ensure the power bids with DSO if no solution has been made.

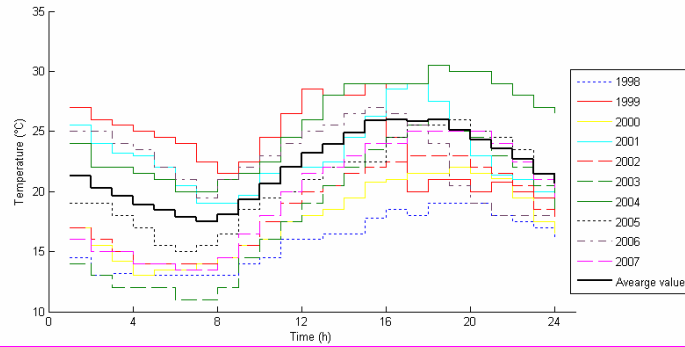


Fig. 2. Example of temperature uncertainty for July, 5-th

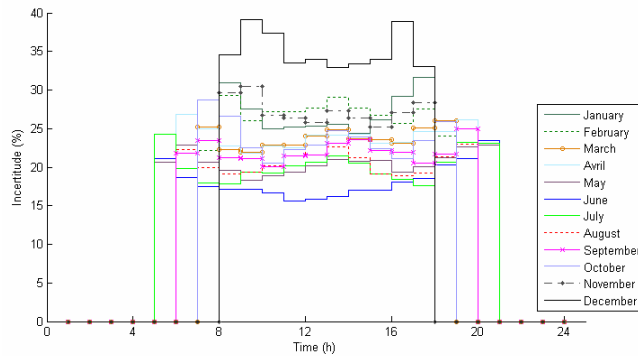


Fig. 3. Uncertainty of solar radiation for the monthly average day

The second kind of uncertainty for the proposed system is the consumption behaviors. Any change in planned consumption leads to modification in operation plan and effectively deviation in injected power to the grid. So, imbalance could appear and PV generator could not satisfy its obligations in ancillary services.

However, it is possible to see that the damage caused by the intermittence of PV source is more important. In the one hand, the values are often bigger. In the other hand, the system has also the load management control mechanism that allows rescheduling the consumption or shedding a part of load if necessary.

#### 4. PROBLEM FORMULATION

The problem of optimal operation of a PV-based system presented previously can be formulated as optimization problem using the Mixed Integer Linear Programming (MILP) algorithm. Its standard form representation is given in [16] as (1).

$$\begin{aligned} &\text{Minimize} && f(x) && (1) \\ &\text{Subject to :} && Ax \leq b \end{aligned}$$

$$A_{eq} \cdot x = b_{eq}$$

$$lb \leq x \leq ub$$

The  $x$  vector (unknown variables) includes hourly operating power of each source: - charging power  $P_{bin}(t)$ , - discharging power  $P_{bout}(t)$ , - consumed grid power  $P_g(t)$ , - surplus power  $z(t)$ , - controllable load power  $P_{LP}(t)$ , - non-controllable load power  $P_{NLP}(t)$ . Each variable is limited to its lower ( $lb$ ) and upper ( $ub$ ) bounds.  $A$ ,  $b$ ,  $A_{eq}$ ,  $b_{eq}$  represent the inequality and equality equation constraints of  $x$ .  $f$  is the vector of objective function.

#### 4.1. Objective definition

The optimization is carried out in two steps:

- *Step 1*: Based on the forecast information (weather, local demand, and electricity prices, etc.), the owner of PV-based multi-source system anticipates the operation plan for his installation for the next 24-hours. The main objective consists in:

- allocating the sources to satisfy the predicted demand and scheduling of local consumption,
- computing the active power bid to communicate to DSO.

The operation plan allows the owner to determine the expected gain  $MB_{S1}$  to maximize:

$$MB_{S1} = \sum_T (z(t) \cdot c_s(t) - P_g(t) \cdot c_g(t)) \quad (2)$$

The first term is the gain of selling the local production to the grid. The second term is the purchasing of grid energy to meet local demand.

- *Step 2*: To deal with the intermittence of primary sources and demand, the owner assesses the risks in order to take the appropriate decision in case of disturbances. As both the change in supply and demand sides makes change in the surplus, i.e. the real injected power to grid, the re-adjustment of the energy allocation is needed and will be progressively carried out in real time control. The objective is to comply with the bid in order to minimize the possible penalty cost:

$$\text{Minimize } \sum_T (|z(t) - z^*(t)| \cdot c_{pen}(t)) \quad (3)$$

By this reason, the effective gain of system  $MB_{S2}$  is defined as:

$$MB_{S2} = \sum_T (z(t) \cdot c_s(t) - P_g(t) \cdot c_g(t) - |z(t) - z^*(t)| \cdot c_{pen}(t)) \quad (4)$$

The first term in (4) is the electricity sold to the network. The second one is the cost of consumed grid energy. And the last one is the balancing costs which are incurred if the expected active power on the day ahead balancing market differs from the real injected active power.

As the objective expression in (4) is not written in linear form, we propose to introduce the variable  $\omega(t)$  so that:

$$|z(t) - z^*(t)| \leq \omega(t) \quad (5)$$

The optimization problem can be translated as:

$$MB_{S2} = \sum_T (z(t) \cdot c_s(t) - P_g(t) \cdot c_g(t) - \omega(t) \cdot c_{pen}(t)) \quad (6)$$

Subject to the constraints (10-19) given in §4.2 and the following ones:

$$\omega(t) \geq 0 \quad (7)$$

$$z(t) - \omega(t) \leq z^*(t) \quad (8)$$

$$-z(t) - \omega(t) \leq z^*(t) \quad (9)$$

#### 4.2. Constraint description

The following constraints are considered.

- Production and consumption balance constraint:

$$P_{Pr}(t) - P_{bin}(t) + P_{bout}(t) + P_g(t) = P_{LP}(t) + P_{LNP}(t) + z(t) \quad (10)$$

- Constraints related to battery operation:

- Evolution of state of charge (SOC):

$$SOC(t) = SOC(t-1) + P_{bin}(t) - P_{bout}(t) \quad (11)$$

$$SOC_{min} \leq SOC(t) \leq SOC_{max}(t) \quad (12)$$

- Charging and discharging process constraint: These two operation modes are quite independent and can not be carried out at the same time. So, it is then expected that pour all  $t$ :

$$P_{bin}(t) \cdot P_{bout}(t) = 0 \quad (13)$$

This constraint is not a linear one. However, it is possible, by referring to [2], to translate it into linear form by introducing a binary decision variable  $\alpha(t)$ , so that:

$$\begin{cases} 0 \leq P_{bin}(t) \leq \alpha(t) \cdot \frac{S_{max} \cdot r_{ch} \cdot \eta_B}{\Delta t} \\ -\frac{S_{max} \cdot r_{dch}}{\Delta t} \cdot \frac{1}{\eta_B} \cdot (1 - \alpha(t)) \leq P_{bout}(t) \leq 0 \end{cases} \quad (14)$$

$$\text{if } \alpha(t) = 1 \rightarrow \begin{cases} 0 \leq P_{bin}(t) \leq \frac{S_{max} \cdot r_{ch} \cdot \eta_B}{\Delta t} \\ P_{bout}(t) = 0 \end{cases} \rightarrow \text{Battery in charging mode}$$

$$\text{if } \alpha(t) = 0 \rightarrow \begin{cases} P_{bin}(t) = 0 \\ -\frac{S_{max} \cdot r_{dch}}{\Delta t} \cdot \frac{1}{\eta_B} \leq P_{bout}(t) \leq 0 \end{cases} \rightarrow \text{Battery in discharging mode}$$

- Constraints related to grid connection:

- contractual limit of consumed grid power

$$0 \leq P_g(t) \leq P_{gn}(t) \quad (15)$$

- Buying and purchasing possibility constraint: imposed by system architecture, these two processes can not be realized at the same time. Similar to (14) and by using a binary variable  $\beta(t)$  we have:

$$\begin{cases} 0 \leq z(t) \leq P_{PV}(t) \cdot \beta(t) \\ 0 \leq P_g(t) \leq P_{gmax} \cdot (1 - \beta(t)) \end{cases} \quad (16)$$

$$\text{if } \beta(t) = 1 \rightarrow \begin{cases} 0 \leq z(t) \leq P_{PV}(t) \\ P_g(t) = 0 \end{cases} \rightarrow \text{The system purchases the PV production to grid}$$

$$\text{if } \beta(t) = 0 \rightarrow \begin{cases} z(t) = 0 \\ 0 \leq P_g(t) \leq P_{gmax} \end{cases} \rightarrow \text{The system imports grid energy}$$

- Limit of injection power to network: To avoid the hard constraints on battery operation (often cause for damage and frequent replacement), we suppose that stored energy in battery is not authorized to be injected to network. The surplus of system is only limited by the PV production availability:

$$0 \leq z(t) \leq P_{PV}(t) \quad (17)$$

- Constraint related to demand side management possibility: load controllability is considered as follows: the end users don't mind the power consumption patterns if the purpose to use the service is satisfied. For example, user expects that the service  $d$  is achieved at  $t = a_d$ , the consumed energy  $e_L^d$  required should be maintained in an appropriate prescribed period  $[a_d - \delta_d : a_d]$  but consumed power would be deferred.

$$\sum_{\tau=(a_d-\delta_d)}^{a_d} P_L^d(\tau) = e_L^d \quad (18)$$

with  $\delta_d$  is the time to realize the service  $d$

However, the energy consumption must be the same as the case without load management:

$$\sum_t P_L(t) = \sum_t (P_{LP}(t) + P_{NLP}(t)) \quad (19)$$

#### 4.3. Resolution of optimization problem

The problem is formulated and implemented in Java. The solver CPLEX Mixed Integer Optimizer [17] has been used to solve the optimization problem. A two-level algorithm is used. In the upper level, the tree of the binary variables is explored by Branch-and-Bound method. At each step of searching, a set of values are set up for the binary variables and a Simplex algorithm is then applied to solve the problem with continuous variables.

## 5. STUDY CASE, APPLICATION AND DISCUSSIONS

The study case is focused on a residential house of about 100 m<sup>2</sup>, having about 92 m<sup>2</sup> available surface for PV installation. Specifically, it is located at North 43° 39' and East 7° 1' with mean daily radiation of 5 kWh/m<sup>2</sup>. The PV-based multi-source system is composed by a 50 modules PV of PW850 equivalent to 4 kWp and a battery storage system of 15 kWh. The system is connected to network with the contractual grid power rate of 6 kW. The householder purchases and sells energy to market whose prices change every hour. The data forecasting gives estimated load demand, available PV production and electricity price in the next figures (Fig. 4 and 5).

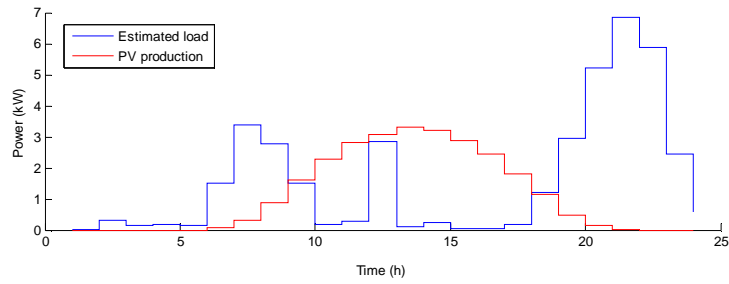


Fig. 4. Forecasting of load demand and available PV production

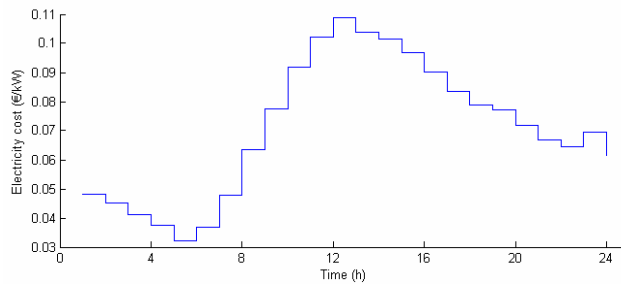


Fig. 5. Profile of electricity price for one day

To anticipate the operation of system, the algorithm gives an optimal use of different available sources, as we can see it in Fig. 6. The total production is calculated by the sum of PV production consumed locally, the consumed grid power, and the discharged power from battery storage system to meet the demand of the house. In parallel, a part of loads is programmed to be used at different moment in the day in order to better utilization of sources (Fig. 7). The surplus is also computed to communicate to DSO. This is the optimal operation plan for the system that the owner makes at the day  $D-1$  for the day  $D$ .

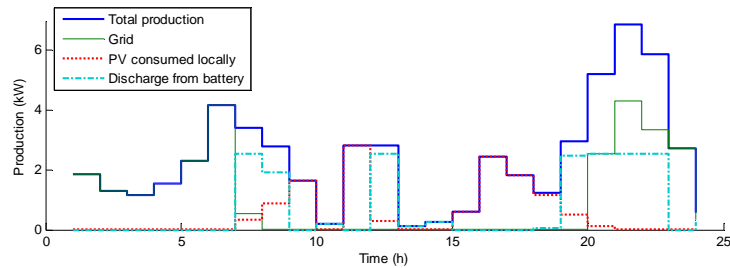


Fig. 6. Optimal operation plan for allocation of sources to loads

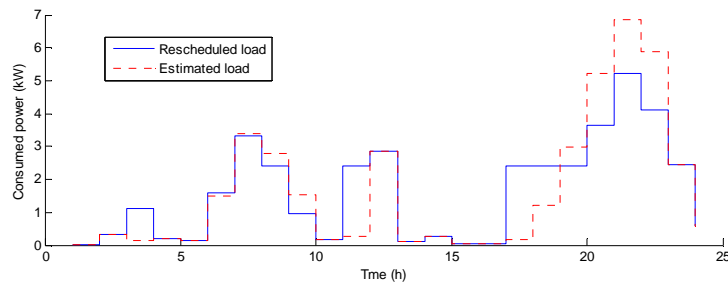


Fig. 7. Load scheduling for better utilization of sources

In the real time operation during the day  $D$ , several uncertainty elements impact on the operation and the profit that could be obtained. The following cases may occur:

- (1). An increase in consumption: the householder uses more energy than estimated. So, the available surplus would decrease in order to compensate (with others sources) the local demand. The impact of this effect is more important in peak hours or in the period where local production is not enough or not available.
- (2). A decrease in consumption: It has no negative impact on profit because the owner of system has several solutions:
  - (2.a) the not-served energy can be then charged into battery to be used later;
  - (2.b) the not-served energy is injected to grid, the owner accepts the penalty if the different between the income and the penalty is positive;
  - (2.c) a part of production is shed.

It is the optimization calculation algorithm that will give the best decision to deal with this event.

- (3). An increase in production: similar to (2).
- (4). A decrease in production: this event is the most for the system. The operation plan needs to be re-calculated for the rest of the day (from instant when incident occurs) to re-allocate the energy from available sources to loads; loads is also rescheduled if possible. The objective is to minimize the penalty cost caused by the fact that injected power diminished.

An operation example scenario is given as follows and in the next figures with three unpredicted events:

- $t = 9$  h: The householder goes out earlier than planned and a load device is then not used. The consumed power by loads reduces about 0.85 kW during an hour.
- $t = 14$  h: A storm occurs that PV production is not available during about an hour, and the next hour the production diminishes about 1.27 kW.
- $t = 20$  h: The householder has an inviter for diner. He needs the electrical cooking stove of about 1.25 kW during an hour.

To deal with these events, the operation plan has respectively called for re-calculated. As the consumption has reduced early in the morning, the algorithm proposes to charge the non-used energy in battery from for later use (Fig.8). No modification has been made in the consumed grid energy and the injection power to grid. At 14-15h the PV production diminishes the injected power to network is effectively reduced (Fig. 9) but the deviation between the effective injection and the predicted value is minimized. Finally, in the evening, when the PV production and the battery storage system are all not available, the best solution is that the house accepts to increase the consumed grid power to meet the local needs. By this way, it is ensured that the operation of system is optimized and the difference between the offer and effective supply is minimized.

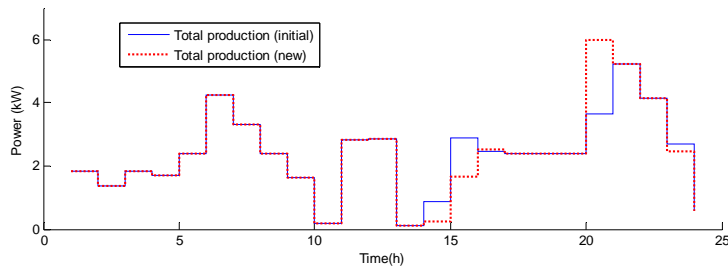


Fig. 8. New plan of allocation of sources to loads

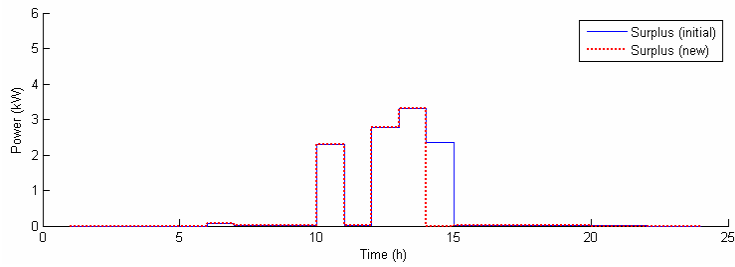


Fig. 9. Injected surplus to grid

Nevertheless, as it can be seen in this example, the available surplus is less than the predicted value that the PV-based system owner has made before and therefore he must pay a penalty. The profit for participating in market system for the day  $D$ , initially estimated of 1.22 €, decreases to 0.5 € (about 60% off).

If electricity market price increases or if the purchasing costs of electricity decreases, this revenue would grow. As we are in an upward energy price tendency [18], the strategy presented in this paper could be more profitable in the long run.

For the larger deviation, the profit would be null or even negative because of penalty cost. The Fig. 10 gives an analysis on the value of profit in functions of possible deviation size and rate penalty cost.

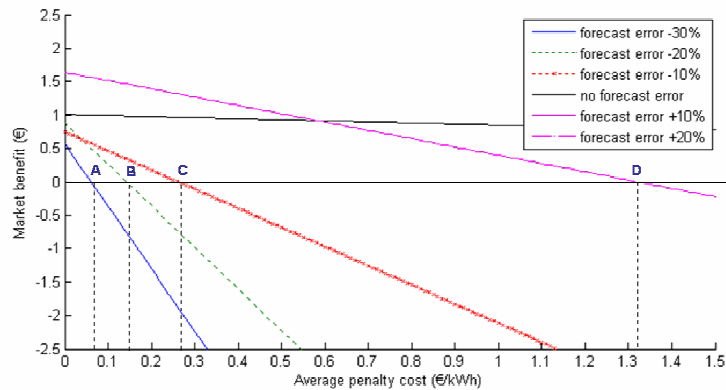


Fig. 10. Impact of PV production uncertainty on profit obtained by participating to power market in function of average penalty cost

A positive impact of uncertainty on surplus (positive deviation) let the benefit positive because of the absence of penalty cost. On the other hand, a negative impact on surplus reduces benefits. The PV owner has to pay an imbalance costs. However, this benefit could stay positive if the imbalance cost is not so high. The determination of thresholds for what the participating to ancillary service and balancing market is profitable is made in table 2.

Forecast error (%)	Penalty or imbalance costs (€/kWh)
-10	[0.07 ; 0.08]
-20	[0.15 ; 0.16]
-30	[0.27 ; 0.28]

Table 2 : Thresholds of imbalance costs

If penalties are lower than these thresholds, for a given uncertainty level, PV owner earns benefits for participating to ancillary services or balancing mechanism. The penalties must be reduced if the uncertainty is great to keep this benefit positive. For example, in France on the balancing market with upward tendencies, the balancing costs of transmission operator could be between 0.07 and 0.24 €/kWh. So, we could see that, with uncertainty, the benefit stays positive.

## 6. CONCLUSIONS

Projecting to the medium term where the attractive conditions for PV production (subsidy, feed-in tariff, obligatory purchase...) will be reduced, the development of innovative energy architecture for residential housing application is needed. The system is composed by PV-based multi-source system and source and load co-management. The optimal energy management processes increase the user awareness of system economic interests. A methodology to compute the most effective solution for such system to participate to ancillary services or balancing mechanism is presented in this paper. The main advantages of this approach are:

- the proposition of a power market design for the distribution system to facilitate the integration of PV-based system to participate to ancillary services;
- the development of an optimization method for anticipating the system operation and dealing with intermittence and uncertainty in order to improve the use of PV energy;
- the analysis of the profitability of the service.

By this way, DSO could quickly ask PV generators to participate to ancillary services or balancing mechanism because of the development of PV. The computational results on a study case illustrate the approach and clearly show that even with the intermittence of primary sources and uncertainty of consumption behaviours, the potential economical interest exists for householder to provide this service.

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