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A Stylized Economic Model on PV Prosumers Encompassing Generation and Storage Economic Requirements, Load Management, Grid Exchanges and Regulation Rules

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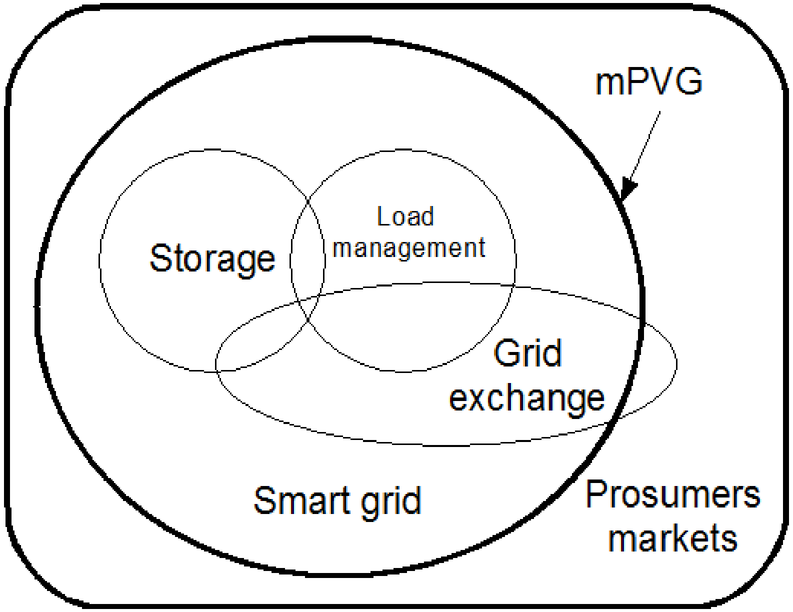
A stylized model to highlight the main economic and regulatory factors shaping micro-Photovoltaic Generation



Components of the mPVG

Elements of the model

Vector (**q**): hourly PV generation in a day (kWh)
Vector (**x**): hourly loads in a day (kWh)

It shows the electricity consumption of the,

* Non-shiftable appliances: lighting, TV set.
* Shifttable appliances:
    · Flexible appliances: their operating level can be changed at will: air-conditioner devices, heating system
    · Deferrable appliances: their energy consumption can be delayed: clothes dryer or garden watering pump, washing machines and dish washers.

Load Management (L^M):

$$L^M = \sum_k \sum_\tau e_t \alpha_t^k \sigma_t^k + \sum_k \sum_{\tau^*} \sigma_t^k + \sum_k \sum_\tau (e_t - a)\sigma_t^k$$

Fine tuned device operation — Curtailment time of use — Appliances feeding from battery

Performance of the battery:

$$\mathrm{B} = \begin{bmatrix} b_1^+ & \cdots & b_{24}^- \\ b_1^- & \cdots & b_{24}^- \end{bmatrix} \quad \text{and} \quad \boldsymbol{\beta}\mathbf{B} \leq b^{max}$$

hourly charging/discharging matrix

b_t energy charging/discharging profiles
β_t charging/discharging efficiencies

Types of grid exchange (exports and imports of electricity)

1

The regulation gives priority to self-sufficiency, or instantaneous self-consumption plus the consumption which uses the previously stored energy.
If there are surpluses, these will always feed the battery.
Electricity will be sold to the grid only when battery is full.
Therefore, exports will play a marginal role, although also imports will be limited.

2

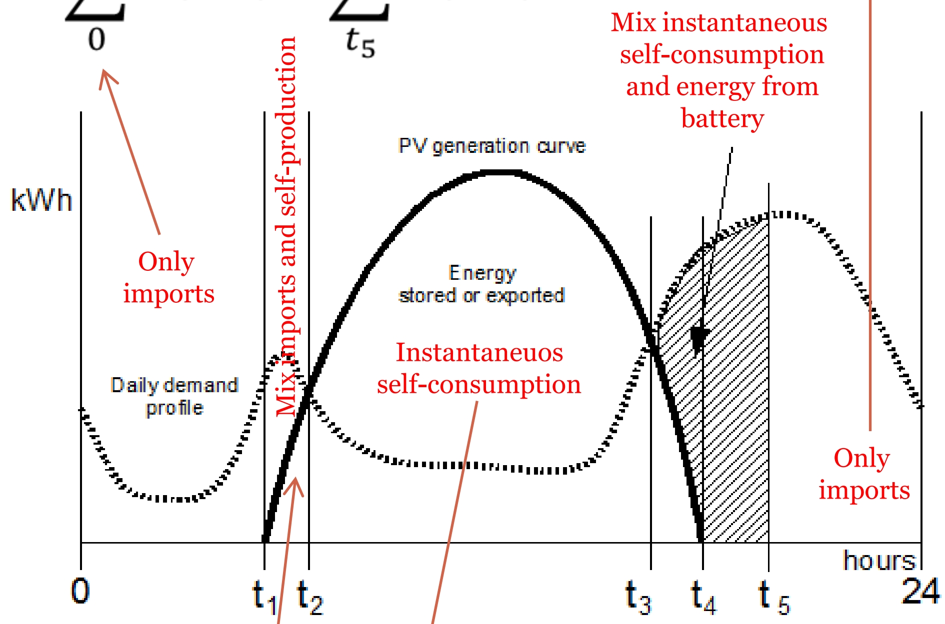
The regulation allows either accumulate the surplus or sell it.
This decision will be taken apart from the state of charge of the battery.
Sales are justified by the price per kWh.
Exporting electricity at a high price implies risk: in the future, it will have to be imported at a (hopefully) lower price.
Information on (wholesale) electricity prices implies connection to a smart grid

3

The regulation allows a free interaction with the grid.
Exports and imports can take place at any time.
Stored electricity can also be sold to the grid.
Information on (wholesale) electricity prices implies connection to a smart grid.
Commercial prosumers

A reference day: the hourly demand is covered with five different possibilities

$$c_t^1 = \sum_{0}^{t_1} m_t \cdot e_t + \sum_{t_5}^{24} m_t \cdot e_t$$



$$c_t^2 = \sum_{t_1}^{t_2} \left(a_G^h / q_t + m_t \cdot e_t \right)$$

$$c_t^4 = \sum_{t_3}^{t_5} \left(a_G^h / q_t \right)$$

$$c_t^3 = \sum_{t_2}^{t_3} \left[a_G^h / q_t + a^h / \beta_t^+ b_t^+ + \varepsilon_t \left(a^h / q_t - w_t \right) \right]$$

The mPVG with self-sufficiency priority

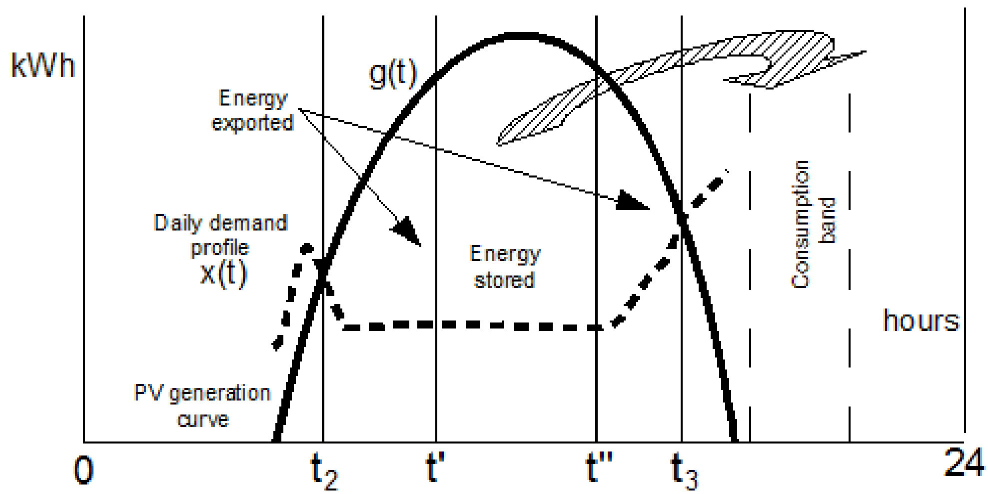
PV plant	Flows of electricity		Load management
It is generating	Electricity surplus	Exports to the grid	Load priority
		To the battery	
	No surplus	Instantaneous self-consumption	Reduction of consumption (imports)
No generation	Battery discharging until its depletion		
	Imports from the grid to be consumed		

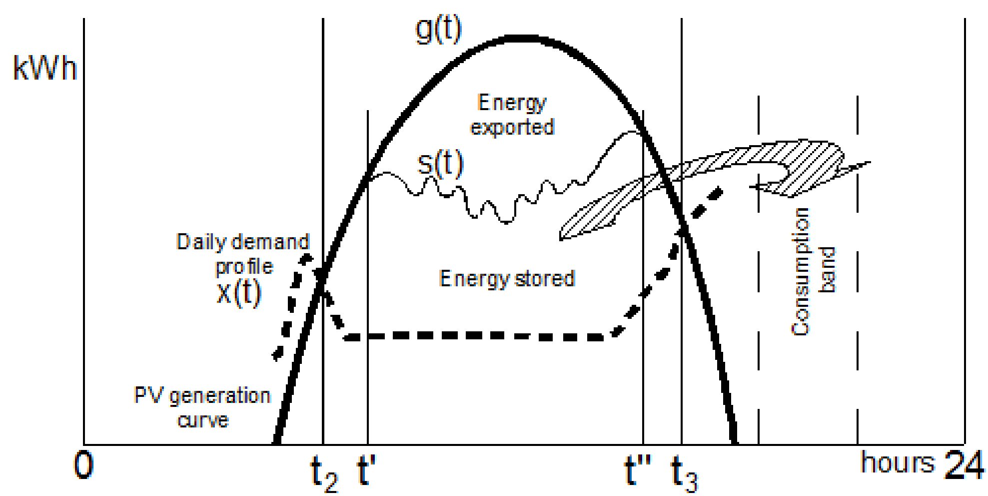
Key economic component: value of the exports

$$c_t^3 = \sum_{t_2}^{t_3} \varepsilon_t \left({a^h}/{q_t} - w_t \right)$$

For $w_t << a^h/q_t$, this value is residual

The mPVG with limited arbitrage (partial self-sufficiency)





In this case the really important criterion is given by the difference between C_t and C_t^*, where C_t^* is the initially expected cost and C_t is the cost which results at the end of the day:

$$\sum_{t_3}^{T} w_t(e_t^* - e_t) - \frac{a^h}{\beta_t^+ b_t^+} - \varepsilon_t \left(w_t - {a^h}/{q_t}\right) > 0$$

The prosumer tries to achieve a value as greater as possible of this expression.
So, the real retail price was clearly lower than expected, and there were exports in the previous hours: decision under risk.
However, achieving a positive value at the end of the billing cycle (or, better, for a whole year) does not seem to be easy.

Main conclusions and further research

- The mPVG plants are complex technological systems.

- The everyday use can be compelling. To transform consumers in prosumers, mPVG management interface should be easy. In this context, aggregators will probably play a key role.

- In self-sufficiency as a priority, load management contributes to the objective. The case of mPVG with limited arbitrage is much more demanding: we have to take decisions on future prices, which leads to a set of decisions regarding load management and the use of battery. Although it is a forecast for the next few hours, this is a decision with some risks.

- Regulatory details related to the design of microgeneration tariffs may only delay, but not remove, the incentive to deploy mPVG.

- There is an increasing analysis of the services that the prosumers may provide (under remuneration) to the electricity system. Prosumers may participate in the ancillary services, including load following or frequency regulation, etc.

- The impact of social factors on mPVG is a subject worth to be analyzed.

Thanks