# DEMAND SIDE MANAGEMENT IN A RURAL AREA

Pedro CASTRO
EDP NEW R&D – Portugal
pedro.castro@edp.pt

Gisela MENDES
EDP NEW R&D – Portugal
gisela.mendes@edp.pt

Clara GOUVEIA
INESC TEC - Portugal
clara.s.gouveia@inescporto.pt

Ricardo ANDRÉ
EDP NEW R&D – Portugal
ricardo.andre@edp.pt

Alexandre NETO
EDP NEW R&D – Portugal
alexandre.neto@edp.pt

André MADUREIRA
INESC TEC - Portugal
andre.g.madureira@inesctec.pt

Olli KILKKI
EMPOWER – Finland
olli.kilkki@empower.fi

Andrea MICHIORRI
ARMINES – France
andrea.michiorri@mines-paristech.fr

Carlos CORREA
ARMINES – France
carlos-adrian.correa_florez@mines-paristech.fr

## ABSTRACT

*In this paper, the authors start by introducing and explaining the concept behind the market business model which was developed and tested during SENSIBLE project. This use case is based on three main pillars: forecasts, distribution system operator tools and retailer requests. The aim of this use case was to define a possible framework and validate its technical feasibility in a real environment.*

## INTRODUCTION

During the last years, we have been witnessing a structural change in the electrical energy system. Although the final product in its basis is the same, electricity, the way it has been produced and consumed has been having fundamental changes. There are several drivers for this change, one of them are the low prices of photovoltaic generators, which enable the final costumer to produce part of his own energy. Moreover, the need for diminishing CO$_2$ emissions leads to the replacement of conventional sources of energy with intermittent renewable energy technologies. Due to its intermittency, the paradigm has changed: now the load follows the production, whereas in the past the production followed the energy consumption needs.

This paper will describe a demand side management use case and present the results from its real-life demonstration during SENSIBLE Project[1]. This project has a demonstrator site in Valverde, a rural area close to Évora, Portugal.

The demonstrator aims to test different kinds of storage solutions distributed throughout the electrical grid and to manage the electricity consumption given the available PV production and storage capacity. Approximately 230 clients are connected to two secondary substations owned by the Distribution System Operator (DSO). From this group, there are 25 low voltage clients with a leading role in this demonstrator.

The use case, which mobilizes client's flexibility, has two complementary goals which benefit the retailer and the grid. The retailer could also be regarded has an aggregator of these 25 clients, without any loss of meaning. Under the scope of the first goal, the retailer will optimize its bids in the day-ahead market taking the: clients' consumption, their flexibility and the PV production forecasts into consideration. On the other hand, the DSO will do a technical validation of the retailer's requests for clients' flexibility. Then, during the day, in an intra-day market, the DSO will monitor the grid and will request client's flexibility when needed. Whereas, the retailer will be able to ask clients to manage their consumption and production to minimize the differences between the amount of energy that was bought, by the retailer, and their present consumption.

## USE CASE TOOLS

### Forecasts

**Client's consumption**

The tool provides forecasts for the electric and heating demand for individual consumers. It uses as inputs:

- Weather forecasts
- Historical measurements

and produces probabilistic forecasts of the two parameters. The tool makes use of machine learning and is able to capture the behaviour of the system (in this case, the electric and heating demand of the building) considering only the measurements. The availability of further parameters can help to improve the precision of the forecast and speed up the learning process. The time horizon can range between 15 minutes to 48 hours and the update rate is of 1 hour. Both parameters are customizable. The tool is based on a spline regression algorithm, chosen in this case for its robustness. It is possible to write the effect of the load $y_t$ at instant $t$ as the sum of functions $f_1, \dots, f_k$ associated with exogenous

---

[1] H2020-LCE 08-14-Storage-Enabled Sustainable Energy Supply for Buildings and Communities

variables $x_t^1, \dots, x_t^K$ and a random noise $\epsilon_t$

$$y_t = \sum_{k=1}^{K} f_k(x_t^k) + \epsilon_t.$$

With this approach, it is supposed that each exogenous variable influence the load independently. It is then necessary to find what the functions $f_1, \dots, f_K$, approximated as splines. The training is carried out thanks to the use of historical data and a 3rd order polynomial is fit to the dataset. Data used as input for each time step are:

- The load measured 24h before, in order to capture daily trends
- The median load of the previous week, in order to capture weekly trends
- Forecast temperature

The performance of the model is reported in Figure 1, in terms of Symmetric mean absolute percentage error (SMAPE) and Normalised root-mean-square error (NRMSE).

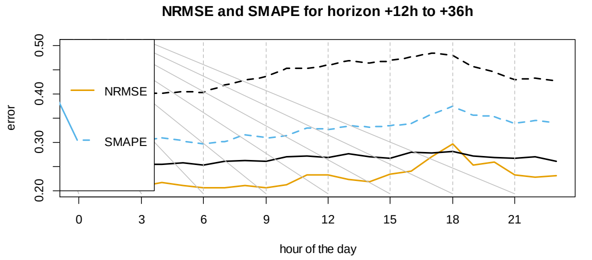


***Figure 1.* Electric demand forecast, errors and comparison with the persistence (in black)**

### PV Production

The PV production forecast tool is very similar to the heating and electric demand forecast tool. It is able to capture the effect of solar trajectory, shadowing by local obstacles, inclination and orientation and the effect of weather forecasts. Model's data are estimated using the most recent data. This solution provided better results, especially for lower forecast horizon at the price of increasing the computational burden.

The chosen statistical model is a non-parametric model which has been considered in estimating the whole power distribution at once. It is based on a kernel density estimator (KDE) and can be written as:

$$y_t = \frac{1}{nh} \sum_{i=1}^{n} K\left(\frac{x_t - x_{t,i}}{h}\right)$$

Where $K$ is the kernel function and $h$ a smoothing parameter.

The exogenous variables chosen for this model are:

- The historical production of the PV plant
- The predicted irradiance at instant t for the location of the PV plant

The performance of the model is reported in Figure 2, in terms of Normalised Mean Average Error (NMAE) and Normalised root-mean-square error (NRMSE).

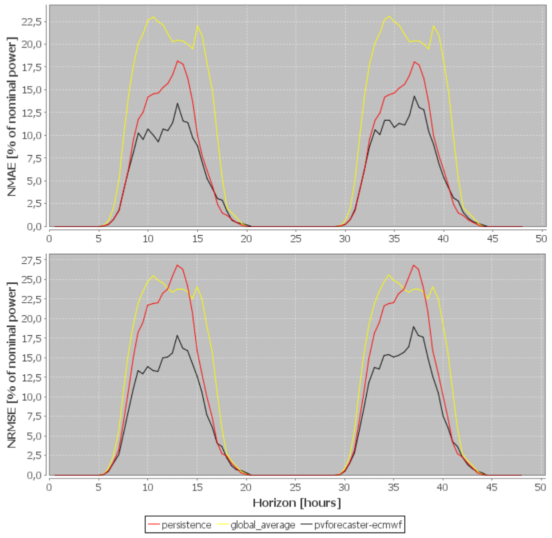


***Figure 2.* PV production forecast, errors and comparison with the persistence (in red) and the global average (in yellow)**

### Client's flexibility – amount and price

Flexibility forecasts are provided for each client and group of clients in order to quantify the flexibility that can be offered on the market or to the DSO for solving network problems. It is composed of six time series for forecast horizons from 12 to 36 hours and with a time step of 15 minutes. The six time series are:

- Maximum allowable power in charge [kW]
- Maximum allowable power in discharge [kW]
- Maximum allowable energy in charge [kWh]
- Maximum allowable energy in discharge [kWh]
- Cost of discharge [€/kW]
- Cost of charge [€/kW]

Maximum charge and discharge power are calculated considering devices (batteries and electric water heaters) rated power and the PV and electric demand forecasts described above. This is necessary since due to household contracted power, the available flexibility depends also on the effective net load. Maximum charging and discharging energy are calculated by taking into account the actual storage capacity of each device and its expected usage profile. This is particularly important for electric water heaters, where hot water consumption modifies the storage capacity. Finally, the cost of charge and discharge is an average value taking into account flexible devices efficiency, losses and aging. This is particularly important in batteries which have a, high and highly nonlinear aging cost depending on operating temperature and depth of discharge.

## DSO Tools Validation

In this context, it is the role of the DSO to perform a technical validation of the market plan for the day-ahead defined by the retailer concerning the flexibility of his clients. For this purpose, the DSO will use the LV optimization tool. This tool aims at optimizing the operation of the LV network making use of the available assets that include for instance storage units connected to the secondary substation or even other storage units connected to an LV feeder. In case there is a technical constraint violation (for instance a voltage value beyond the admissible limits or the overload of a power line or cable), the tool will mobilize the flexibility available from the domestic clients.

Then, in the intra-day, the implementation of the plan defined in the day-ahead is followed in order to check for deviations that may occur in real time operation. In case there are significant deviations, additional flexibility is mobilized through the Home Analytics.

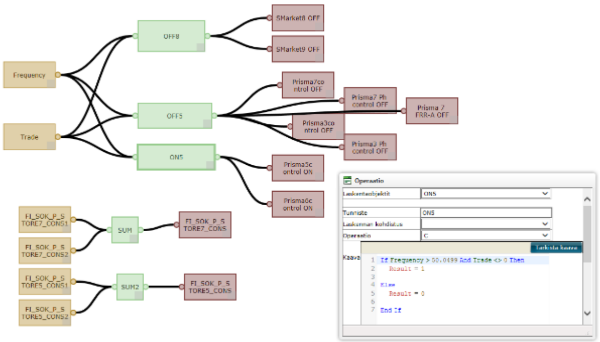
The tool is based on a multi-temporal Optimal Power Flow (OPF) algorithm [1]. The multi-temporal nature of this tool is due to the additional inter-temporal constraints that are added to the optimization problem by introducing and modelling storage devices (including their SoC limits as well as its charging and discharging efficiencies).

Also, a three-phase model of the LV network is required in order to represent the actual operation of this grid turning this into a full three-phase multi-temporal OPF.

## Retailer participation

The retailer evaluates based on the prevailing market prices the cheapest hours when to charge the energy storages, and the hours with highest prices to discharge the storages. The retailer calculates from the amount of flexibility indicated by the forecasting tools the constraints of the storages and requests flexibility from an Energy Market Service Platform (EMSP).

The EMSP handles the contracts and flexibility requests of the retailer and the flexibility auction mechanisms.



Laskentaobjektit: ON5
Tunniste: ON5
Laskennan kohdistus:
Operaatio: C

```
If Frequency > 50.0499 And Trade <> 0 Then
    Result = 1

Else
    Result = 0

End If
```

*Figure 3.* **EMSP flowchart**

The EMSP (Figure 3) requests from the DSO tools to assess if the requested flexibility and resulting forecasted consumption curves are suitable from the grid constraint perspective. The EMSP then receives grid flexibility requests from the DSO based on which an auction is performed which satisfies the grid requests.

During the intra-day the EMSP aims to maintain the initially forecasted consumption of the consumers within the expected consumption. Again, the DSO can also request changes to consumption to grid nodes based on its needs. The retailer requests changes to the consumption and the EMSP then auctions the changes to the clients with the lowest costs while taking into account the flexibility requests of the DSO.

## DAYLY OPERATION

### Day-ahead

The day-ahead process starts at 11.30am every day. Armines, the forecasts-provider, shares in a Real Time Platform (RTP) the data concerning the quarter hourly forecasts of clients’ consumption and PV production. Additionally, calculates the amount and cost of their flexibility. This last one is based on their tariff and the inherent wear of the appliances which provide the flexibility.

Afterwards, Empower, who developed the Energy Market Service Platform (EMSP), performs an auction between clients. Given the prices of their flexibility, calculated on the previous step, and based on historical data of the prices for the wholesale market, it will allocate increasing amounts of upwards flexibility (to increase consumption) requests, from the cheapest clients to the most expensive ones, matching these requests with the cheapest hours of the following day. Moreover, the EMSP also allocates downwards flexibility requests to the most expensive hours. This way, the energy bought for this portfolio of clients is optimized, shifting consumption from the most expensive hours to the cheapest.

The next step consists on a validation of the requested flexibility done by the retailer, i.e. the optimal power flow developed by INESC TEC plans the operation of the LV network considering the DSO owned storage devices and the market platform results. If some technical violation is detected, the DSO will request for additional load flexibility to solve the problems.

An example of an operation plan defined by the DSO is presented next assuming an extreme scenario where there is a voltage violation. In this scenario, the demand flexibility is also used since it was not possible to solve the voltage violation problem resorting only to the scheduling of the only storage device available. It is considered that 1.5 kW of maximum flexibility in the time period between 19:00 and 23:00 is available from each customer. The energy storage management strategy, for this scenario, is shown in Figure 4.

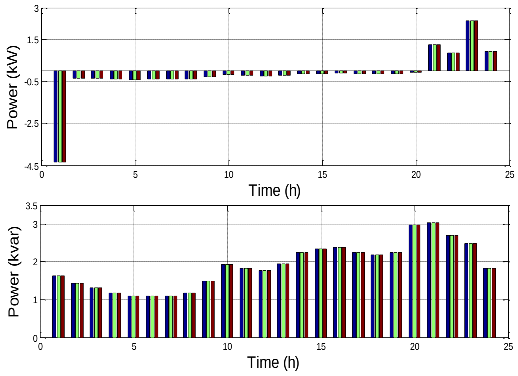


***Figure 4.*** **Active and Reactive Power Set-points for Storage Device**

In Figure 5 the active power set-points for one of the three flexible customers considered during the allowed time frame is presented. As previously explained, this flexibility was mobilized in order to solve a voltage violation that occurred in the end of the day.

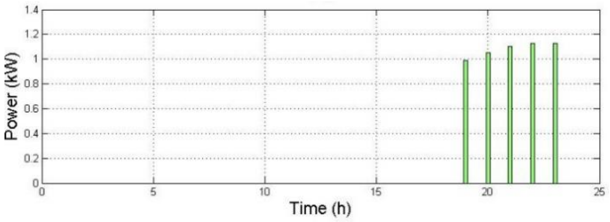


***Figure 5.*** **Active Power Set-points for Flexible Customer**

Finally, the last phase of the day-ahead workflow consists on publishing the set points for the involved clients on the RTP. These setpoints are sent to clients, during the following day by the Home Analytics, a platform created by Armines. These process of defining the setpoints for the following day ends at 12.00am, i.e. twelve hours before the first hour of the following day.

### Intra-day

Then, during the day, and starting at midnight, the intra-day process is initiated. At the beginning of each hour (HH:00) forecasts for the next period of six hours are updated on the RTP. Using these new forecasts power flows are run once again and if any technical problems are foreseen new set points for each home are defined by DSO tools. These set points are sent at the quarter of hour (HH:00, HH:15, HH:30, HH:45).

On the retailer's side, the EMSP will check during each interval of 15 minutes the real consumption and will compare it with the predicted one, which is assumed to be the one that was bought on the wholesale market. In case of deviations greater than a predefined percentage, client's flexibility is requested in order to minimize these deviations. The EMSP will send these requests every 4 minutes after the DSO tools publish their requests, i.e. HH:04, HH:19, HH:34 and HH:49. The aim of the EMSP is to minimize during each hour the difference between the energy bought on the day-ahead and the consumption until the end of the respective hour.

## USE CASE RESULTS

Until now the correct implementation of the day-ahead market was already tested, and the ambition is to validate the rest of the use case during the demonstration phase of the project. In Figure 6 it can be seen that having the spot price curve for the next day, and defining price limits to request flexibility, both to increase and decrease consumption, a curve of flexibility requests can be defined. The retailer will ask clients to shift their consumption from the most expensive hours to the cheapest hours. Here clients were asked to turn-off their water heaters and to discharge their batteries. The set points, to charge and discharge are automatically sent by Armines' Home Analytics tool to each one of the clients, who was awarded with flexibility, in the auction.

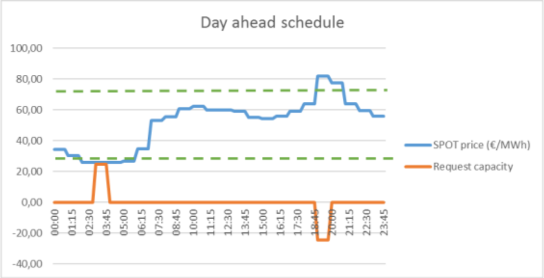


**Figure 6. Day ahead allocation of flexibility**

## CONCLUSIONS

The work developed in this SENSIBLE's project Use Case can be regarded as a possible methodology and framework to enable an active participation of clients in energy markets while having, at the same time, the DSO monitoring and validating all the flexibility requests. This will create new sources of revenue for clients. Ultimately, these new sources of revenue will incite the investment in home energy storage and energy production, which may contribute to diminish the dependence on fossil fuels and, therefore, contribute to the decarbonisation, given that costumers invest in renewable energy sources. Additionally, it also allows DSOs to differ investments which they would have to do sooner in their grids.

## REFERENCES

[1] H. M. Costa, J. Sumaili, A. G. Madureira, and C. Gouveia, "A multi-temporal optimal power flow for managing storage and demand flexibility in LV networks," in *2017 IEEE Manchester PowerTech*, 2017, pp. 1-6.