USING SIMULATED PREDICTIVE LOAD CURVES TO IMPROVE DSO'S NETWORK DEVELOPMENT PLANNING METHODS INTEGRATING SMART GRIDS FUNCTIONALITIES

Aurélie FERRAGE,
Maxence BOCQUEL
ERDF – France
aurelie.ferrage@erdf.fr

Nicolas KONG
ERDF – France
nicolas.kong@erdf.fr

Thibaut BARBIER,
Robin GIRARD
Mines ParisTech - France
thibaut.barbier@mines-paristech.fr
robin.girard@mines-paristech.fr

ABSTRACT

The actors in the electrical system face significant challenges related to new uses (electric vehicles, net-zero energy building...) and new EU energy objectives. The Distribution System Operator (DSO) must adapt network planning methods to support the energy transition. Therefore ERDF and Mines ParisTech have developed a new Bottom-Up method to forecast electricity consumption needs at the local level.

This approach named MOSAIC has been successfully tested through field experiments and developed in a collaborative partnership with the Administration of Urban Community of Lyon. It opens interesting perspectives for the development of credible estimations of local energy planning schemes using smart grid solutions. The paper describes the model principles and presents the results and comparison with measurements.

INTRODUCTION

The energy transition is a real opportunity for DSOs to challenge their planning methods. DSOs need long term estimation tools that are able to integrate local energy planning scenarios and convert them into useful data for network planning.

This paper explains how ERDF (the main French electricity DSO) and Mines ParisTech (a research institute) developed and tested MOSAIC, a tool simulating the annual electricity load curve of a building or a small district.

Such a tool is very useful for ERDF to improve its planning methods. Indeed, current planning methods for distribution network developments mainly consider the peak power demand. An annual load curve would provide much more valuable information for network planning. For example, by analyzing the shape of the peak of the daily demand curve, ERDF could find out if Demand Response solutions would be appropriate for this building connection. Furthermore, by comparing the simulated annual load curve and predictions on renewable electricity generation, ERDF could know if there will be periods of renewable electricity overproduction, which could undermine network stability.

1. A BOTTOM UP SIMULATOR INCLUDING MICROSCOPIC AND MACROSCOPIC INPUTS

The electricity demand can be seen as the sum of microscopic contributions, with different physical consumption devices. But it can also be influenced by statistical parameters such as economic growth, national mean temperature etc.

We have chosen a hybrid approach that is a compromise between complete and complex physical models, and fast simplified statistical models to simulate the electricity consumption.

Hence, the technical objective is to be able to simulate with very short computation time (i.e. a few tens of seconds for simulating one year of consumption with a one hour time step resolution) the individual electricity consumption of thousands of customers (both in residential and tertiary sectors). It includes physical models of electrical appliances, and buildings. Each microscopic contributor of the aggregate load curve is spatially identified and its individual load curve can be known. At the same time we should be able to modify inputs and perform sensitivity analyses quite rapidly. The simulation has to be done with a variable time step for a maximum flexibility to deal with different aggregation levels. The simulator relies on large databases for the input data: population census, DSO's client information, meteorological data such as temperature or irradiation data etc. Also microscopic inputs have to be considered, like local specificities on climate, on consumption habits or buildings.

As models have many parameters, a calibration from measurements and literature results is necessary. Finally, the simulator and the involved models have to be as generic and open as possible to account for evolutions in the context and be able to integrate new models (i.e. heat pumps, electric vehicles, etc.).

1.1. Models and implementation of the simulator

The developed simulator implements the following models for electrical appliances of the residential sector: TVs, washing machines, dishwashers, computers, lights, swimming pools, dryers, ovens, cooktops, refrigerators,

freezers, water heaters, electric heaters, heat pumps, air conditioners and miscellaneous (standby).

The consumption devices are modeled by elementary models such as block profiles of power. Figure 1 depicts the example of the model proposed for a washing machine: the first power block corresponds to heating the water with a resistance, the second block models the washing cycle with a constant power of motor, and the third block models the spinning with a constant power of motor.

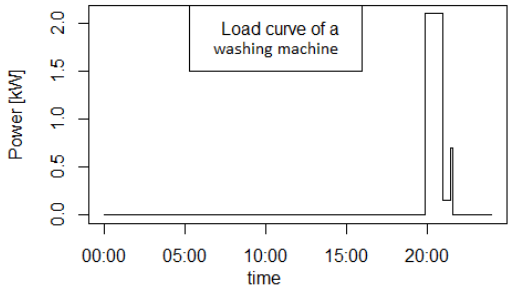

Figure 1: Example of load curve of a washing machine modeled by a constant block of power.

The simulator also implements tertiary sector electricity consumers, with the categories: offices, teaching/research, shops, shops with food, restaurants, hotels and charging stations for electric vehicles (EV).

We have chosen an architecture with a computation core as fast and simple as possible implemented in a low level language: C++. This core allows the physical models of electrical appliances to be run rapidly. A special feature is that the consumption patterns of electrical appliances used in the simulator can be easily changed if needed.

In order to deal with big data, and to be able to make statistical computations, the calculating core has been interfaced with R software, which is an open source numerical simulation platform.

1.2. Different steps of simulation

The electrical load curve simulator is implemented into three blocks (static characteristics, simulation of electrical appliances operation, and energy computation), which are illustrated in figure 2 and explained in the following subsections.

Static Characteristics

This part of the simulator prepares the model of each consumption device with the necessary parameters, e.g. power of the TV, minimum and maximum duration for the daily use of a TV etc. The values of the inputs are set by existing databases and measuring campaigns. Then, these consumption devices are grouped to simulate a consumer (e.g. a consumer has two TVs, a washing machine, some lights).

Simulation of electrical appliances Operation

A given consumption pattern for each electrical appliance is set. This profile is a combination of daily, weekly and monthly profiles, and is interpreted in the calculation core as a probability density for launching the given electrical appliance. A Monte Carlo simulation is performed where the number of sampling in the simulation period is chosen as an affine trend with the number of inhabitants in the simulated house. The start date and duration sampled in this launch phase are always independent from any time step: here is just memorized the start dates, duration and power of operation (called “instance”) of all consumption devices generated in the previous step.

The electric heaters, heat pumps and air conditioners are modeled by a first order “RC” model taking into account assembly thermal characteristics, outdoor temperature, solar irradiation and temperature set point.

Computation of Energy of each Consumer on a chosen Temporal Grid

This step is the moment when the temporal resolution is chosen: a temporal grid is created, with a given time step, and all the “instances” previously described are integrated in the chosen temporal grid, making a final vector of energy at the chosen temporal resolution. The energy is simply calculated by multiplying the power and the duration of this power, at each time step. This specific approach allows us to change the time step without making all the previous steps of simulation again, as all the instances are memorized.

1.3. Evaluation and calibration of results

The simulation is done in a bottom-up way, consumption device per consumption device, housing per housing, and tertiary consumer per tertiary consumer. This leads to a

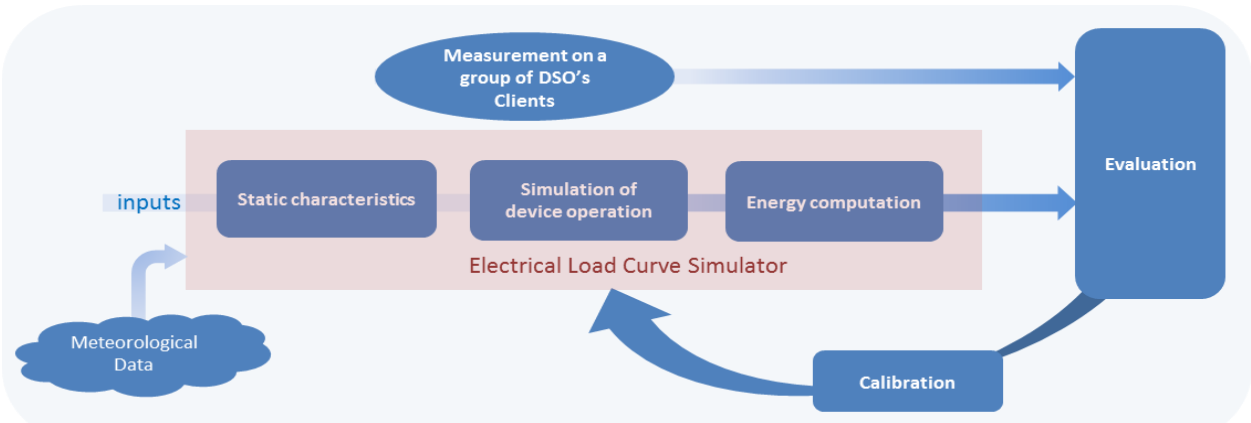

Figure 2: Illustration of the approach used for electric load curve simulation

considerable amount of output results, which are memorized and can be evaluated by a comparison with a reference case that can come from a group of DSO's customers as illustrated in figure 2. These evaluation results can be used in order to calibrate or re-adjust the different parameters of the simulator in order to minimize the gap between its output and the reality [1].
This simulator we are describing is named MOSAIC. We explain now a concrete application and how we can use it.

2. DATA MANAGEMENT

Simulating the electricity load curve of a building requires a proper description of the building both in terms of physical characteristics and in terms of the type of energy used.
The quality of the simulation depends on the quality and quantity on the input data. Yet all the data required to perfectly describe a building or a district are very difficult, even sometimes impossible, to gather. This is especially the case when we try to simulate a building that does not yet exist.
One of the great features of the MOSAIC simulation tool is its ability to work even with very little input data.

2.1. Building characteristics

The MOSAIC simulation tool works by simulating each "house" one after the other. A "house" can be a real house, but it can also refer to other types of premises such as an apartment, an office, a shop, a cafe, a restaurant, a hotel room or even an electric vehicle charging station.
MOSAIC only requires little information describing the houses to be able to simulate an electric load curve: type of house, surface area, position in the building (ground floor, intermediary floor, or top floor), year of construction, location in France (using the department code) and overall building energy efficiency performance (in case the building has been refurbished)
These necessary data can be completed by other information if available such as the house thermal inertia or the height beneath the ceiling (mostly for ancient buildings with very high ceilings).

Existing buildings
Different options are available to find these data for existing buildings. Most of these data are available thanks to the city government in the local tax databases. Some urban planning agencies might have information on building characteristics especially if these buildings are located in an area of significant importance for the city (e.g. a business district, the city centre, a recent urban development area...).
In case this level of detail is not easily available, further data treatment can be necessary to describe the area. Such data treatment can consist in estimating the number of apartments using the total residential area surface and INSEE (National Institute of Statistic and Economy) statistics for apartment size distribution in the city. The number of floors in the building can also be estimated by comparing the total usable surface with the floor space.

Future buildings
It's trickier to describe future buildings than existing ones. Indeed they don't exist yet and depending on the construction project maturity level, very little information may be available.
Using MOSAIC to simulate a predictive electricity load curve therefore requires making some hypotheses on the future building characteristics.
The surface area of each "house" can be estimated from global figures using the same hypothesis than for existing buildings. Building energy efficiency performance largely depends on the legal framework for construction and refurbishment. Yet local governments can also influence this parameter. As MOSAIC's simulations are done very rapidly for buildings, it's possible to make different scenarios on the buildings' energy efficiency performances and compare the impact of this parameter on the electric demand load curve.

2.2. Energy vector per usage

Existing situation
Through MOSAIC, all consumption devices are simulated one by one. If some devices, such as white goods in apartments or computers in offices, are always running on electricity, heating, cooling, and hot water heating can use other energies.
Thus MOSAIC needs to know which proportions of the simulated houses use electricity for these usages.
As an electricity DSO, ERDF only has an overall vision of a customer electricity usage (through the electricity meter). Knowing the proportion of clients that use electricity for heating, cooling or hot water heating is therefore quite difficult.
Some solutions can be used to overcome this difficulty. We have developed models that can estimate the part of the electricity consumption that depends on the outside temperature. Hence it is possible to know the proportion of electric heaters in a given group of clients knowing their load curve. The quality of these models depends on the quantity of consumption data available. They are thus particularly reliable for buildings with Linky Smart Meters.
It's also possible to analyze other energies' consumption figures if they are available and to deduce if electricity is used for thermal usage.

Future situation
The choice of the energy vectors used in a building or an apartment is influenced by many factors such as building efficiency standards and regulations, availability of energy networks (for gas, district heating and cooling), local energy policies, energy prices and even personal preferences.
One of the main benefits of MOSAIC is its ability to

assess the influence of these choices on the electricity demand load curve of a building or an area.

2.3. Standby consumption calibration

Standby electricity consumption represents a significant part of a building's energy consumption. MOSAIC has some default values of standby power of different types of usages. It's also possible to use existing building historical annual electricity consumption data to calibrate standby power to a specific case.

2.4. Result visualisation and analysis

As we saw, MOSAIC can assess the electrical impact of scenarios describing the future of an area in terms of energy efficiency performance and/or energy vectors. We developed a dynamic interface able to present the outcomes of the MOSAIC simulation. This interface allows to visualise many simulations on the same graph, to compare the scenarios' impacts and to identify the more desirable ones.
The main interest of this interface is to be able to visualise very easily different temporal scales by zooming on the curve.

3. EXPERIMENTATION IN LYON

ERDF and Grand Lyon are experimenting new energy planning methods through the European project TRANSFORM. Thanks to this project, we were able to gather the necessary data to test MOSAIC both at the building and district scale.

Figure 3 - Part Dieu Area

3.1. Calibration with a building

The DESAIX building has been used for small scale calibration. DESAIX is a 1960s gas heated building with 280 apartments (total 17,000 m²) and 800 m² of offices.
This building was chosen for the calibration of MOSAIC because many data were available to describe it and because there is a big refurbishment and expansion project.
Measuring instruments have been installed for the two secondary substations bringing power to the building.

This measure campaign started in October 2014 and went on for three months. Figures 4 shows the comparison between a simulation made by MOSAIC (with a standby power calibrated using DESAIX's historical electricity consumption) and the real electricity demand load curve.

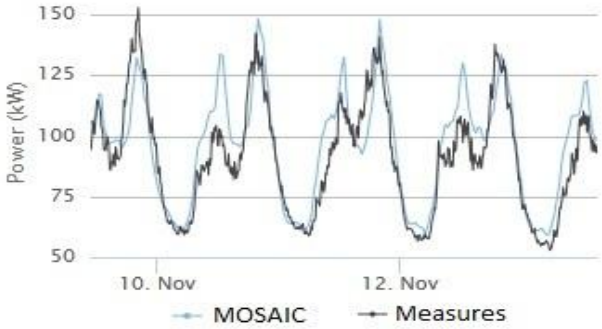

Figure 4 – Calibration of MOSAIC for DESAIX building

A statistical error analysis using the Mean Absolute Percent Error (MAPE) method gives a MAPE of 10.4% which is very good for a time-series forecast.

3.2. Calibration at the District Scale Test with the Lyon Business District

Thanks to the TRANSFORM project, Grand Lyon and ERDF have been exchanging data regarding the current and future state of the Part Dieu business district. This district is of particular interest as it will drastically change by 2030 (1,000,000 m² build, 150,000 m² demolished, 270,000 m² refurbished).

Testing MOSAIC at the scale of Part Dieu was harder to do than it was for the DESAIX building. First, Grand Lyon had to gather the necessary data for around 80 building blocks. As explained in paragraph 3 some of the data were extracted from existing databases and some had to be estimated from national figures (global surface area per usage for the block…).
Figure 5 shows the result of the MOSAIC simulation for the existing entire Part Dieu district.

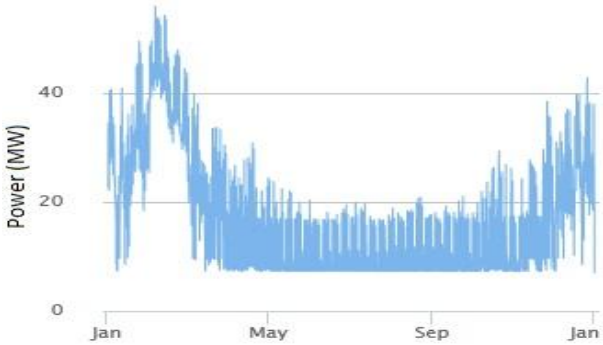

Figure 5 - Simulated load curve for existing Part Dieu district

The next step of the MOSAIC test in Lyon on the first half of 2015 will be to compare this result with measures from the primary substation high voltages feeders that

bring power to the area.

3.3. Integration of local energy planning scenarios

ERDF is determined to support Grand Lyon development in its energy transition. Indeed there is currently a big urban development project in Part Dieu aiming at doubling the available building surface by 2030 while keeping the 2010 energy consumption level. This cooperation could benefit both the City and the DSO by getting a vision of the future energetic situation of this area. This can help to improve network planning and assess the most interesting evolution scenarios for the area integrating smart grids solutions.

As explained in the previous part, we are able to calibrate MOSAIC on the existing Part Dieu district. Then the challenge is to simulate the future energy planning scenarios. For this purpose, Grand Lyon collaborates with HESPUL, a not-for-profit organization specialized in rational use of energy and renewable energy. They established four scenarios for the evolution of the Part Dieu district in 2030. The scenarios differ on two parameters: level of building energy efficiency and part of electricity in the buildings' energy mix (see figure 6).

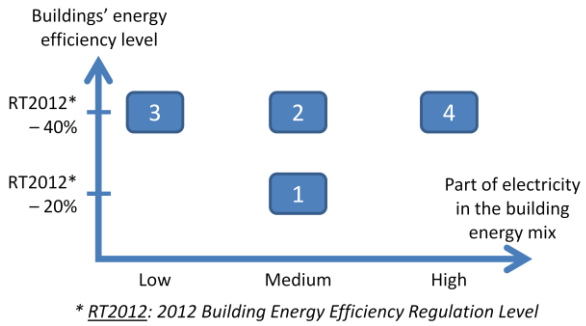

Figure 6 - Part Dieu district evolution scenarios

Finally, with a description of each refurbished or new building, we will be able to simulate the most impact of the four scenarios with our tool MOSAIC.

However municipal infrastructures and facilities like theatres, swimming pools or public lightings are difficult to simulate. We have to continue working on refining MOSAIC models.

CONCLUSION AND PROSPECTS

The experimentation of the MOSAIC modeling tool for a district of Lyon met ERDF's objectives: forecast the local electricity demand of a town district. We were able to validate this concept of aggregation profiles of electrical equipment and consumption statistics.

The work on MOSAIC will therefore continue in order to build an industrial version considering renewable electricity production, Demand Response and other smart grid solutions. These solutions could be used as new ways to optimize investments for local scale planning [2]. Indeed they can help to reduce peak electricity demand [3] and enable new added value services for the end users such as Electric Mobility. This is why we believed that these first results are very promising and tools like MOSAIC will play an important role in future network planning methods.

ACKNOWLEDGMENTS

The experimentation of MOSAIC in Lyon in the TRANSFORM project was only possible through collaboration with Grand Lyon and Hespul. As partners of ERDF in Transform, Grand Lyon, with the help of Hespul gathered the necessary data to feed MOSAIC.

REFERENCES

[1] T. Barbier, R. Girard, F-P. Neirac, N. Kong and G. Kariniotakis, 2014, "A novel approach for electric load curve holistic modelling and simulation", *Proceedings MEDPOWER 2014 conference*, manuscript 221.

[2] A. Battegay, N. Hadj-Said, G. Roupioz, F. Lhote, E. Chambris, D. Boeda and L. Charge, 2014, "Impacts of direct load control on reinforcement costs in distribution networks", *Electric Power Systems Research*, 120 (2015) 70–79

[3] S. Levaufre, G. Pelton, F. Gorgette, A. Fontenel, 2014, Simon Levaufre et al., 2014, "Residential load management strategy for local network optimization", *Proceedings CIRED Conference 2014*, paper 0374