IMPACT OF THE PLUS ENERGY BUILDINGS ON THE VOLTAGE PROFILE OF THE DISTRIBUTION NETWORKS

Marc PETIT
SUPELEC – France
marc.petit@supelec.fr

Xavier LE PIVERT
CEA-INES – France
Xavier.lepivert@cea.fr

Alain GUIAVARCH
CEP – MINES ParisTech - France
alain.guiavarch@ensmp.fr

ABSTRACT

This paper presents the impact of a large integration of plus energy households in a LV distribution network. First the household model is described in detail, and then LV network is described. Our study is focused on the voltage level and the risk of overvoltages. The results show that a large integration is possible.

INTRODUCTION

The increasing demand of electricity requires new production capabilities. Nevertheless the building of new classical groups (thermal, hydro or nuclear) can be difficult then new production sources must be considered. The environmental considerations have allowed the development of new solutions such as winds farms – the main solution in the world with 94000 MW set-ups in the world in 2007 – and photovoltaic (PV) panels. This last solution allows a larger installation on urban environment as PV could be installed on each building or individual household. Up to now the PV installation level is quite low in the world due to its higher cost and its lower energetic yield than wind farms, but implementation programs supported by national governments should allow a very fast PV extension.
A plus energy building produces electricity with its PV, but is also a very low energy consumer thanks to a higher thermal insulation and passive solar gains. Originally the distribution networks were designed with a radial topology with power flows from the substations to the loads. Then the high voltage point was at the substation, and the network topology was chosen to respect the voltage limits along the entire network. Step by step the management of these networks is going to change with reverse power flows and possible changes in the voltage profiles.
Over the past ten years numerous papers have been published to study the influence of photovoltaic distributed generation in the MV and LV distribution networks [1-5]. [1] proposes an analytical method to determine the limit value for the insertion of distributed generation in a LV network. [2] shows overvoltages for large PV integration but few details about the network length and the PV generated power. The originality of this paper is based on the coupling of the building modelling (standard and plus energy) with the electrical network simulation. The results will then be based on realistic buildings profiles. Our paper will present the influence of the rate of plus energy household on the voltage profile, to identify the risks of overvoltages or undervoltages. The voltage limits are given by the EN50160 standard: 400 V ± 10%.

HOUSEHOLD MODELLING

Tow types of buildings were modelled (a plus energy house and a standard house). Both buildings were simulated with Comfie, a multizone dynamic simulation tool dedicated to the thermal simulation of buildings [6]. It takes also into account hourly occupancy schedules, and the environment (meteorological data or shadings for instance).

Plus energy buildings modelling

Plus energy buildings produce more energy than the energy consumed over the whole year. This concept can be applied on any type of building (housing or offices for instance), provided its total energy demand is as low as possible. A passive house is a building which typically requires less energy than 15 kWh/m² of living area for the annual heat load. This concept has been applied and validated on hundreds of houses erected for the last 15 years throughout Europe, but especially in Northern Central Europe.

Electricity consumption curve

The building selected in this study is composed of two attached individual houses, which can be inhabited by 5 persons each. The whole building was modelled and simulated, but in this paper the parameters and the results are given for one dwelling only, with a living area of 157 m². The building is south oriented, and is supposed to be located in the South (Nice) to increase the impact on the distribution network. The house was designed according to the Passivhaus standard.
The household electricity consumption was modelled assuming the occupants use efficient appliances. The modelling is based on statistical data deduced from a monitoring campaign carried out in France in 1998 [7] leading to an hourly consumption profile with monthly variations. The resulting total annual electricity consumption is 2 840 kWh (sum of the resulting annual household electricity consumption, 2.44 MWh, and heat pump consumption, 400 kWh). The hourly consumption profile is given in figure 1, showing an hourly peak load of around 800 W. This maximum is reached in January, when the household electricity consumption is the biggest (particularly for lighting), and the heat load significant. For the remaining months of the year, the heat load is too low to have an influence on the monthly profile.

PV production curve

All roofs point to the south and the surface is covered by 45 PV panels for a 36 m² area. The inclination angle is 45°. The characteristics of each PV panel are: area 0.7 m², yield 14% and peak electrical power 100 W. Thus the maximum peak power of each household is 4.5 kW. An inverter with a nominal power of 4 kW feeds electricity into the grid. The efficiency is function of the power load at the input. A default ratio (3 %) is added to take into account other losses (cable losses and mismatch losses). The hourly generated electricity is simulated using the "one diode" [8]. The generation curve over one year is given in the figure 1.

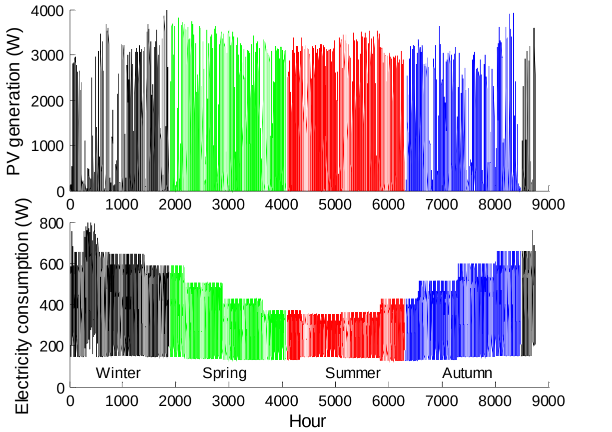

Figure 1: hourly profile of the PV generation (upper) and electricity consumption for the plus energy house

Table 1: electricity balance of the plus energy house

Consumed annual energy	Generated annual energy (PV)
2.85 MWh	5.7 MWh

Standard individual household

Consumption curve

The building is designed according the French current thermal regulation. A gas boiler produces heat for heating and hot water, and in this case the thermal needs don't influence the electricity consumption of the building.

The household electricity consumption is modeled with the same kind of data as those used for the plus energy house, but the appliances are less efficient. The resulting annual household electricity consumption is 4.23 MWh, and the hourly peak load is around 1.05 kW.

DESCRIPTION OF THE LV DISTRIBUTION NETWORKS

The MV/LV transformer (400 kVA) is connected to the medium voltage network. Then the primary voltage will depend on the loads and can vary in the 19 kV-21 kV range. Generally, these transformers are built with an off-load tap changer (0; ±2.5%) where the tap depends of the transformer location in the feeder (near or far from the substation). In this study the MV voltage level is equal to 21 kV and the transformer tap changer is 0%. If other values

Table 2: feeders characteristics.

Feeder	length	max distance from busbar	loads number
feeder n°1	720 m	325 m	14
feeder n°2	60 m	60 m	2
feeder n°3	1.8 km	549 m	29

Table 3 : cabled lines characteristics

Cable	R (Ω/km)	X (Ω/km)	C (µF/km)	I_{max} (A)
95 mm²	0.32	0.1	0.1	235
150 mm²	0.21	0.1	0.1	300
240 mm²	0.125	0.1	0.1	390

are used, it will be specified in the text.

The LV urban network is 100% underground and its length is 2.58 km. The network has three feeders (figure 2) and its characteristics are given in the table 2. The cables parameters are given in the table 3.

The nodes have been numbered according to the following rule: the busbar is the number *1* and the other nodes are numbered to respect that a receiving node has a number higher than a sending node (if we consider a power flow from the busbar to the loads). The branches are identified by their receiving node number.

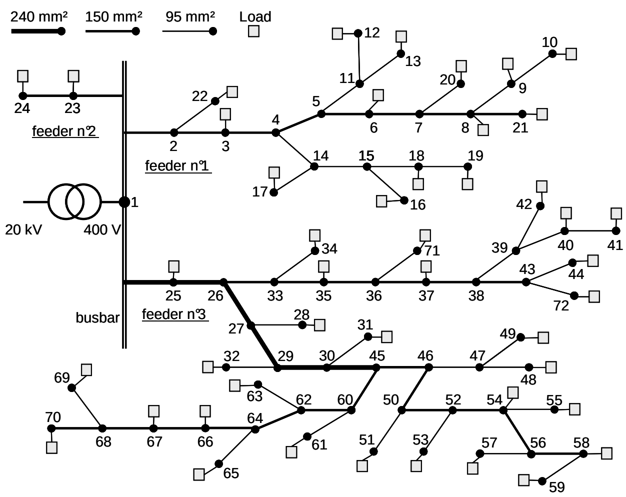

Figure 2 : LV network topology with its 3 feeders and 45 households

Some results will be presented as function of the electrical distance from the busbar. This distance is the product of the line length by the cable resistance (inductance is neglected).

METHOD

The present study is based on a deterministic approach: the load profiles of the various buildings (or households) have been modelled and a deterministic load flow has been performed. The network is supposed to be perfectly symmetric and, only 3-phases loads and generators are considered. Distributed generators (PV) have a unit power factor. To take into account a dispersion between the different households we consider a normal distribution based on the consumption and generation characteristics presented previously. Each power value of the household

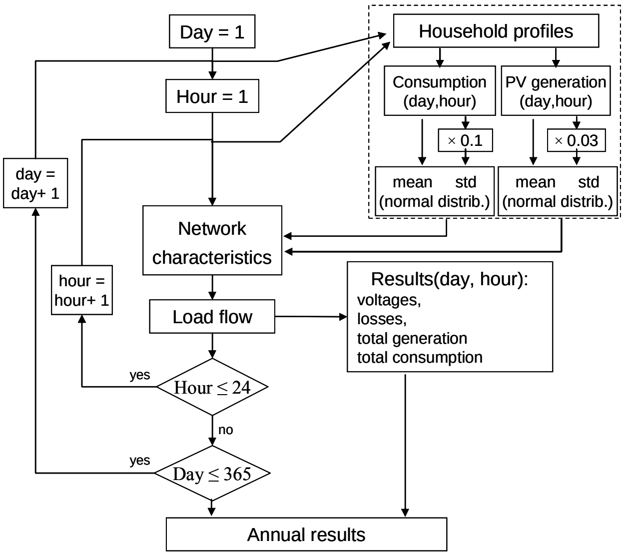

Figure 3: flow chart of the simulations

model will be the mean value of the distribution. The standard deviation will respectively be equal to 10% of the mean value for the consumption and 3% for the PV generation. The flow chart of the methodology can be summarized in the figure 3.

RESULTS

In the following we present the influence of the positive households on various parameters:

- voltage profile as function of the node or electrical distance from the busbar;
- annual losses as function of the rate of positive household;
- influence of the MV voltage and the transformer tap changer (-2.5%, 0% and +2.5%).

Two base cases will be considered: network without positive household (only standard household) and network with 100% positive households (without standard ones).

Base cases

Network with standard households

All the 45 households are standard with no generation. The MV voltage level is equal to 21 kV and the transformer tap changer is 0%. Then the busbar is the high voltage point and its value is closed to 420 V. The lower voltage point is at the node n°69, with a 4.5V voltage drop (figure 4). The voltage profile is presented in the figure 4, the lower figure allowing to distinguish the three feeders. The annual energy consumption is 188 MWh, and the line losses are equal to 0.54 MWh what is due to a low current at the busbar (< 80 A).

Network with 100% plus energy households

All the 45 households are "plus energy" with PV generation. In the present case, the maximum overvoltage is 426 V at the node n°69 (figure 5). The annual energy balance is

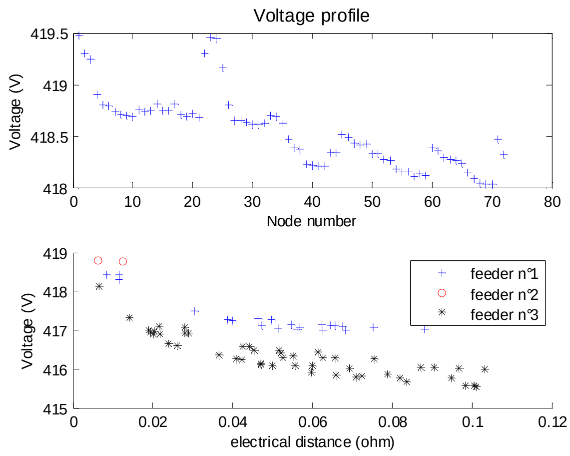

Figure 4: voltage profile for the higher consumption point as function of the node number (upper) and electrical distance from the busbar (lower). Standard households.

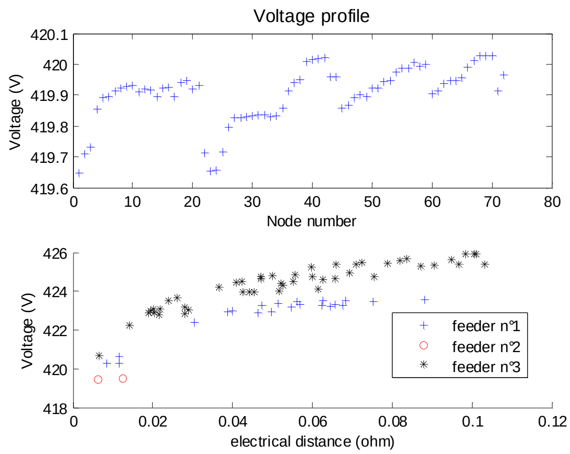

Figure 5: voltage profile for the higher overvoltage point as function of the node number (upper) and electrical distance from the busbar (lower). 100% plus energy households.

positive with 127 MWh injected in the MV a network. The line losses are now equal to 1.5 MWh with higher current than previously at the busbar.

If we compare the feeders n°1 and n°3, it can be seen that, for a same electrical distance value, the overvoltages are higher in the former feeder because the households density is higher.

As the MV voltage can change in the {19 kV – 21 kV} range, we have studied the minimum and maximum voltages in the network for various tap changer settings.

Table 4: minimum and maximum voltage values in the LV network over one year for different MV voltages and several tap changer settings. Network with 100% plus energy households.

HTA level	19 kV			20 kV			21 kV		
LV Xformer Tap changer	-2.5 %	0 %	+2.5 %	-2.5 %	0 %	+2.5 %	-2.5 %	0 %	+2.5 %
Voltage max value (V)	378	387	396	397	406	416	416	426	436
Voltage min value (V)	366	376	386	386	396	406	406	416	427

For the present network, the voltage is always inside the limits given by the EN50160 standard (table 4).

Influence of the plus energy households ratio

In the present case the location of the plus energy houses is randomly chosen. The table 5 shows that the PV generation allows to reduce the lines losses, with a minimal value around a 20% insertion rate. Above this value the PV generation increases and thus the line current, what increases the losses. Originally the MV/LV transformers are consumer nodes. In the present case, the generation becomes higher than consumption when the rate is higher than 60%. For a 60% insertion rate the energy balancing at the substation is around zero.

Table 5: various data as function of the rate of positive households. The annual energy at the substation becomes negative when the MV/LV node generates more than it consumes.

Rate (%)	0	20	40	60	80	100
network losses (kWh)	545	390	442	675	1065	1505
annual energy at the substation (MWh)	192	128	64	0.2	-63	-127
peak power at the substation (kW)	49.4	46.6	48.6	84	120	153
max voltage (V)	419.8	420.3	421.9	423.8	425.3	426
min voltage (V)	415.6	415.8	416.1	416.4	416.6	416.7

Case of a an increased PV generation

Now we consider a 100% integration rate with a higher PV production that could be due to both a higher PV panel's number and a better yield. Let us note that the PV generation is increased for all the houses. We consider an increase of respectively 30 – 50 and 80%. The figure 6 shows that an increase in the PV generation will be a problem if the MV voltage is equal to 21 kV with a +2.5% tap changer. The maximum increase is 140%.

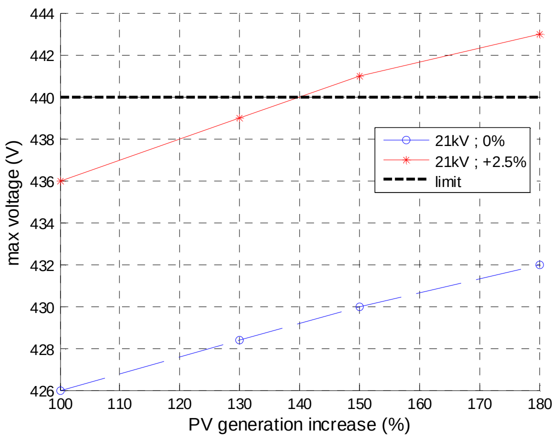

Figure 6: maximum voltage in the network as function of the PV generation increase for a 100% plus energy household rating. Two values of the transformer tap changer have been considered: 0% and +2.5%. The MV voltage is 21 kV.

CONCLUSIONS

The large insertion of plus energy households in a LV distribution network will induce larger voltage variations (undervoltages and overvoltages) than in a classical network without positive households. Nevertheless the voltage will remain in the standard range (400 V +/- 10 %) if the feeders are not too wide. The variations of the MV voltage level and the choice of the LV transformer tap changer is also an important factor. Then the positive households' integration could be made easier, (i) if the number of LV substation is increased to decrease the feeder length, (ii) if LV transformers with on-load tap changer are used, and (iii) if some storage devices were used to smooth the voltage variations.

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