CORRELATION BETWEEN LOAD DENSITY AND VOLTAGE DROP

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ABSTRACT

Equilibrium between MV and LV grids is an important parameter of European-like grids. As new use of electricity develops quickly, this paper analyse the advantages and drawbacks in modifying the voltage margins to LV consumers. The aim is to quantify the physical impact on grid length, number of substations and losses.

The analysis is based on a geometric model with proposed parameters supposed to be representative of four typical dwelling configurations. Main conclusion is that when density is high enough, building strong grids is fine, because it reduces losses for low costs. But when density is lower, it is not worth making too long grids with too many substations. To do so, sufficient voltage margins have to be dedicated to LV grid development.

INTRODUCTION

Voltage drop is one of the major constraints on distribution grids. On French low voltage (LV) grid, customer's voltage has to be kept between 207 and 253 V (+/- 10% around nominal voltage). Medium voltage (MV) and LV grid development rules imply that there are maximum values of voltage drop (rise) permitted along LV grid. When voltage constraints are detected, network reinforcement has to be done through two kind of operation: **using larger conductors (or new feeders)** and/or **creating new secondary (MV/LV) substation.**

Those two operations have also an impact on technical losses on LV grids, which is part of the economic equation for all distribution companies. As size of conductors and substation density are also parameters that enable to reach a certain **level of energetic performance** on distribution grid, **voltage drop is correlated to consumption density.**

The status of on load tap changer in primary substations is set for the whole year, so that the voltage at bus bar is almost constant. If maximum voltage drop on MV grids is reached, LV grids have to be developed in order to reach a **maximum value for voltage drop of 9 %,** depending on primary substation tap changer value. This value is **lowered to 7% to allow producer integration** on distribution grids, as defined in [1].

Efficient planning needs to set long term costs to a reasonable value with proper short term investments. Thus one question has to be asked: what is the **best target structure for future LV grid?** What is the physical impact of **reducing LV margin for customers?**

Cost of network components may be different from one company to another, which affects equilibrium between voltage levels. But some principles must be applied all over the world**: costs results from creating (or renewing) substations and lines, and from technical losses.** Costs are supposed to be mainly linked to the number of substation and grid length. So the optimal solution cannot be the grid with the largest cross section, as this paper proves that its length is increased.

CALCULATION DESCRIPTION

Automatic grids generator algorithm has been developed. Its input parameters are based on a **set of nodes** separated by given distances and associated with load curves. Possible paths are also defined. Grids are automatically built on those data, for different **number of substations** and **target values for grid losses as parameters.** Then load flow calculations are made on generated grids, which are in consequence characterised by electrical indicators, such as **lowest node voltage**, losses in transformers and cables, and physical indicators such as **grid length** and number of substations.

INPUT PARAMETERS

Load curves can be built on the basis of workdays and week end curves (48 values each, one per half hour), multiplied by seasonality factor (52 values, one per week). The accuracy of this model is not the point of this paper, such load curves are supposed to be realistic enough for load flow calculations. Example of load curve analysis can be seen in [2]. Load curve can be associated with a power factor, resulting in a reactive load curve.

In this study case, one standard household is supposed to consume energy with a load profile based on:

- **Specific energy :** 3000 kWh (tan φ = 0,4)

Specific energy is the energy consumed by all appliances excepted water heating and heating. Those loads can be for example fridge, lightning, TV, computer, or oven. Consumption is supposed to be concentrated around 7 am and 19 am during the week, and more flattened during the week end. No significant seasonality is applied to the curve.

- **Water heating :** 2000 kWh (tan φ = 0)

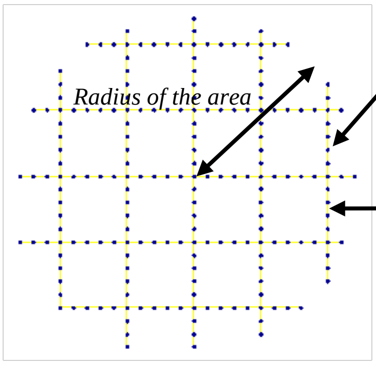
Water heater energy consumption is supposed to be concentrated at night, beginning at midnight and lasting 3 hours. Slight seasonality is applied to the curve, as water is colder during the winter.

- **Heating :** 3000 kWh (tan φ = 0)

Heating is supposed to be lowered during the night all days, and lowered during the day during workdays. Strong seasonality is applied; heating is turned off from April to September.

The resulting load curve has a maximum power value of almost 3 kW.

The set of nodes is made of the **locations representing dwellings,** connected by **possible paths representing the streets.** The set of nodes is defined by the size of the area studied (radius), the distance between two nodes (two buildings) and the number of nodes per street (fixing the shape of the paths). A load curve is associated to each node.



AUTOMATIC GRID BUILDING

Once the input parameters have been set, it is possible to build several grids, entering a **number of MV/LV substations**, and then **increase cross sections of cables** to reach an entered value of losses.

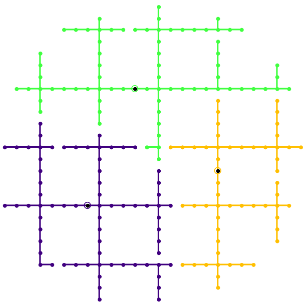
Cables and transformers are ones of the following types, which are commonly used on French grids.

Nominal power (kVA)	No load losses (W)	Losses due to load (W)	ucc (%)
50	125	1100	4
100	210	1750	4
160	300	2350	4
250	425	3250	4
400	610	4600	4
630	860	6500	4
1000	1100	10500	6

Cross section (mm²)	Resistance (mΩ/m)	Reactance (mΩ/m)
35	0.868	0.1
70	0.443	0.1
150	0.206	0.1
240	0.125	0.1

Locations of substations are determined by a **k-mean method**, with the number of substations as the k factor. This method consists in setting transformers at a random location, and splitting nodes in groups depending on their nearest substation. Substations are then moved to the nearest node from the barycentre of their groups of nodes. Repeating this operation several times allows separating nodes in groups, and finding a convenient location for the substations.

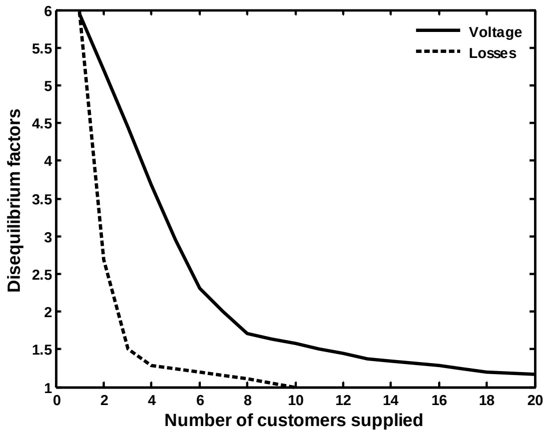
Second step consists in making the **grid grow from the substation to the loads**. Nodes with a transformer are supposed to be connected at first. Then if a node can be connected to an already connected node via a path, the node is connected and the possible path becomes a cable. If two paths can connect a node, only one of them become a cable, and is selected at random. All cables are supposed to have the minimum available cross section, and transformers are chosen so that their nominal power is the smallest value greater than the maximum apparent power flowing through them.



At this point, it is possible to calculate a load flow, but the result has little chance to be realistic, as losses and voltage drop are far beyond acceptable value. **Thicker cables have to be used.**

LOAD FLOW CALCULATION

In LV grids, disequilibrium between phases has a major impact on voltage drop and losses. When power flows in one phase, and current comes back to transformer via neutral wire, voltage drop and losses are multiplied by a factor 6 (at least). When several households are supplied by one cable, there is high probability that the power flows more or less equally trough the three phases. As a consequence, **disequilibrium factor depends on the number of customers supplied by the cable, from six** or more if there is only one customer **to almost one** if there is a lot of customer.



Thus, the load flow used in this paper makes an **equilibrate load flow** using backward forward method, and then voltage drop and losses on each cable **are multiplied by a factor** (one for voltage drop and one for losses), depending on the number of customer supplied by the cable. Disequilibrium factors are parameters of the calculation.

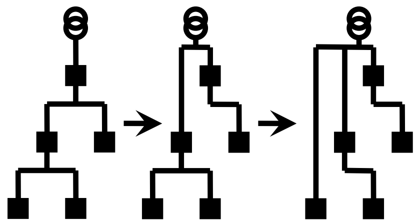
Results of the load flow calculation are: losses in transformers, in cables and maximum voltage drop.

INCREASING CABLE CROSS SECTIONS

The load flow calculation associates for each cable the value of grid losses. These losses can be reduced by increasing cross section of cable by a factor equal to the ratio of previous section divided by new section. The most logic strategy is to sort cables on losses criteria, and apply the most effective increasing operation per square millimetres of cables, until losses are reduced to the target value.

But as there is a maximum size of conductors, most effective operation can be to increase conductor's volume by using new cables in parallel to existing ones (create new feeder), rather than increasing the size of the conductors in the end of feeders, which is subject to low currents, and low losses. That is the key point of this paper: **increasing the volume of conductor brings to build longer LV grids.**

The creation operation of new feeder is based on the principle of the **deconstruction of the tree like structure** to split the feeder in two feeders, as equilibrate as possible.



FOUR DIFFERENT DENSITIES

In this paper four different load densities are considered. Input and calculation parameters are defined below. Those four load densities represent four typical dwelling configurations.

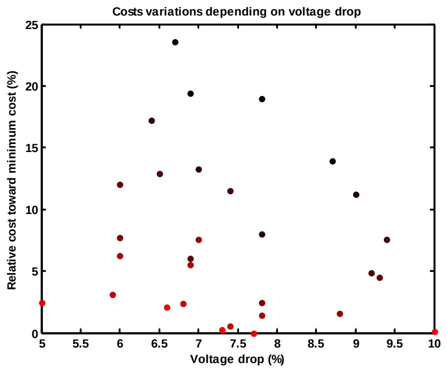
A Dispersed individual dwelling
One house contains one household which load curve was described before. Houses are quite far from each other, so there is low street density, and 240 mm² cables cannot be used (only overhead lines can be used in fields).
B Grouped individual dwelling
Houses containing only one household are close form each other. There are several houses per street, 240 mm² can be used.
C Small buildings of collective dwelling
Small buildings containing 5 households are close to each others. Disequilibrium factors are reduced, and the load curve has to be multiplied by 5.
D Buildings of collective dwelling
Buildings containing 10 households are close to each others. Disequilibrium factors are reduced, and the load curve has to be multiplied by 10.

	A	***B***	***C***	***D***
Number of loads per street	**1**	**3**	**3**	**3**
Distance between loads (m)	**300**	**60**	**60**	**60**
Total consumption (GWh)	**3,4**	**6**	**30**	**61**
Consumption density (GWh/km²)	**0,089**	**1,2**	**6,2**	**12**

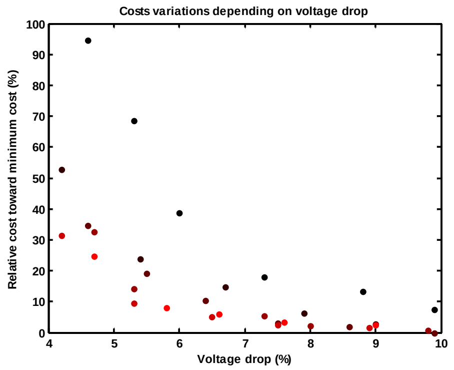
RESULTS

Following curves are built by using costs per substation, grid length and losses (hidden in this article). It is then possible to view the evolution of costs with voltage drop. **MV costs are not considered in this calculation.** Red dots correspond to higher number of substations, which implies MV costs.

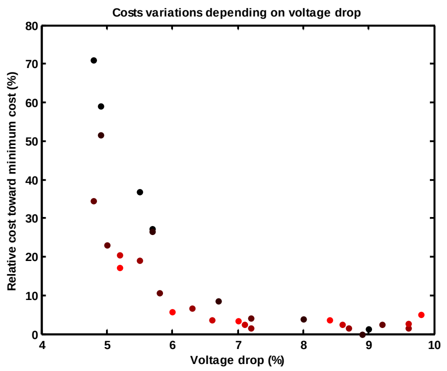
Density A



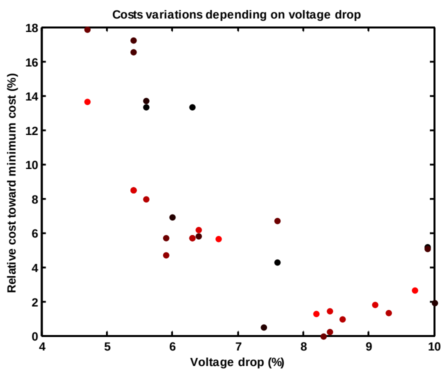
Density B



Density C



Density D



PERSPECTIVES

The equilibrium between voltage levels is an important issue for 230V, three phase grids, such as European ones. From a macroscopic point of view, according to [3], there are major differences in European countries. Reader should remind that Great Britain uses 11 kV whereas the others use 20 kV, so British transformers may be smaller, and more numerous.

Country	Population Billion inhab.	LV length x1000 km	Length m/cap
France	62.8	700	11
Italy	60.6	800	13
Germany	82.3	1100	13
Great Britain	58	400	6.9

Those differences are due to population repartition, and planning rules. As costs are increased by using longer cables and more substations, distribution companies should master the increase of costs due to voltage margins reduction. **Macroscopic figures should be handled with caution, as length can vary for very different reasons.**

CONCLUSIONS

Reducing LV margins causes significant increase in **LV length and number of substations.** As building stronger low voltage grids reduces losses in high density areas (D), using more feeders is suitable (resulting in longer grids). Substations can be designed with a wide range in the case of large cables use. It seems to be the best structure, because space for technical building is expensive in high consumption area, and in this context MV and LV grid length are short.

When density is very low (A), voltage constraints are high because of the disequilibrium between phases. Those constraints, and protection issues, make distribution companies use **many transformers**, which **transfer grid length from LV to MV**. Losses are higher for this kind of dwelling, for low power transformers are less efficient and they are not fully loaded.

Potential savings in LV costs are more important in medium density context (B and C), which may be urban or rural. In this context, voltage margins should not be reduced.

REFERENCES

[1] JP. Sigal, 2011, *MV and LV voltage settings*. ERDF

[2] JP. Zimmerman, 2009, *End use metering campaign in 400 household in Sweden - Assessment of the potential electricity savings*. ENERTECH

[3] 5th CEER benchmarking report on the quality of electricity supply 2011