IMPACT OF LOAD DISPERSION ON GRID LENGTH

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ABSTRACT

Comparing performances and costs is a centre of interest for all regulators and distributions companies. This paper focuses on medium voltage grids, and tries to explain the differences in length that can be observed in European countries. Electric supply disturbances and costs are supposed to be related to those lengths.

The analysis is based on a geometrical model, where parameters such as substation and load densities, or number of feeder, can vary. Main conclusion is that MV grid length is linked to dwelling surface. Natural characteristic such as load dispersion, and distribution companies structuring action such as introducing new substation or new feeder have second order impacts on grid length, with the same order of magnitude.

INTRODUCTION

While comparing macroscopic technical figures of two distribution companies, such as grid length, great difference can be observed in those values even if **correction ratios** are applied, based for example on the number of customer or on the surface of the area supplied by the company. Concerning MV grid length, it is quite obvious that the ratio of length divided by the number of customer will be higher in rural areas than in urban ones. Thus one question comes to mind: are macroscopic figures different because companies develop grids with a **different philosophy or thanks to territory differences?**

Basic grid structuring consists in gathering loads around **primary substations and backbone lines** made of thick conductors. Number of substation and number of feeders are parameters of grid structure which gives medium voltage (MV) grids its capacity and performance. First analysis in this paper quantifies the **effect of adding substations and feeders on grid length.**

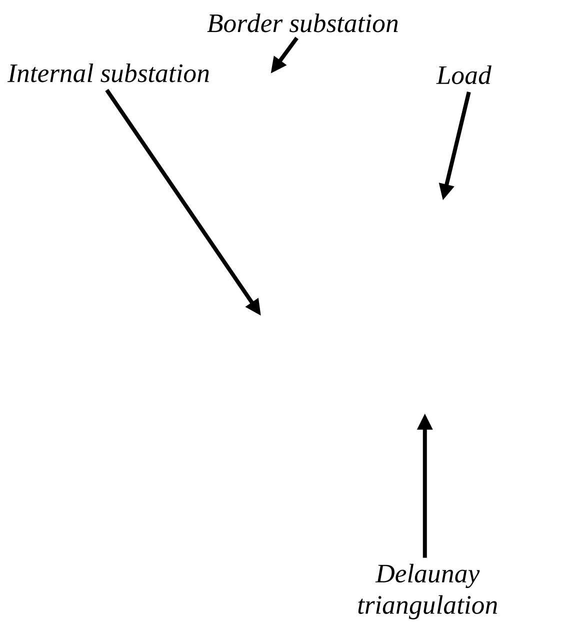
Dispersed loads also have an effect on grid length. Variation of length due to the concentration degree of loads is an input parameter to distribution companies. Costs, continuity of supply and capacity are dependant from this territorial characteristic. Second analysis in this paper is the **evolution of grid length with territory.**

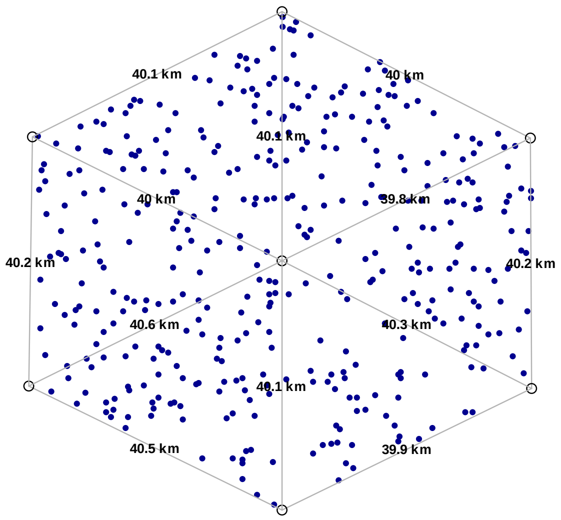
CALCULATION DESCRIPTION

Automatic grids generator algorithm has been developed. Its input parameters are based on a **set of nodes and substations.** This set of nodes representing loads is contained in an area which limits are fixed by substations. Surface of this area can be calculated, and it is then possible to define a **load density**. Grids are automatically built on those data, for different **number of feeders.** Generated grids are characterised by cost related physical indicators such as **grid length** and **number of substations**, and quality indicators, such as **maximum length per feeder**.

BUILDING THE TERRITORY

Territory is built by entering border substation, and filling the internal space with loads and internal substations. The result can be seen on the figure below, particular directions are drawn between substations (gray). Those directions, on which the distance is written, are given via **Delaunay triangulation.** They are the basis of backbone lines.





AUTOMATIC GRID BUILDING

A basic grid can be built from the territory, using principles which are close to **Prim algorithm.** It is a method to connect nodes via a tree. It consists in sorting segments between two nodes on their length, and make the tree grows from one node (chosen at random) by connecting nodes one by one from already connected nodes, using the shortest segment available. The tree built from Prim algorithm has two major properties: its length is the minimum that permits to connect all the loads together (so called **minimum spanning tree**), and if this tree is unique the result of the algorithm **does not depend from the first node chosen** at random.

But the tree given by Prim algorithm is not realistic enough as a grid. In reality the power flows on backbone lines, on which the high currents causes voltage drop and losses. As a consequence, **backbone lines have to be drawn straight from one substation to another.** Feeders are often associated by pairs coming from two different substations to provide **secondary supply in case of failure.**

In this paper Prim algorithm is adapted to match a more realistic design. The backbones, defined by Delaunay triangulation, allow creating a high number of potential nodes, where loads can be connected. Load can also be connected to any other load. Two distance matrix are built: distance to backbone points, and distance between loads. The pure Prim algorithm would have used only the second matrix.

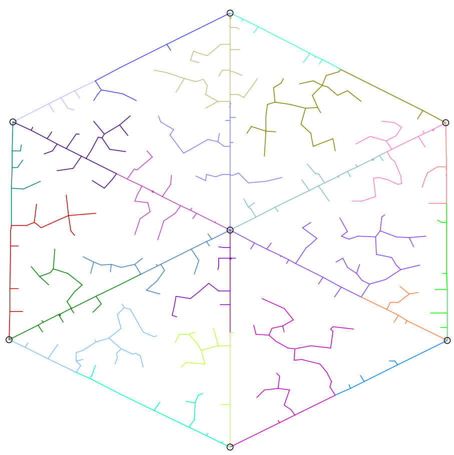
The algorithm does the following operations for each step until all loads are connected:

- If the smallest distance is a distance from **one load to one node of backbone**, the load and the backbone node are considered as being connected.
- If the smallest distance is a distance **from one load to another already connected load**, the non connected load is considered to be connected and the segment between the two loads becomes one line of the grid

There is no need for initialising the algorithm by picking up a node to make the tree start growing. The algorithm will always begin by connecting the closest load from one backbone.

A simple tip permits to **speed the algorithm**: after having calculated the two distance matrix, only the ten smallest distances should be stored in memory. The operation of finding the smallest distance at each step becomes then much faster. Empirical tests show that the result is exactly the same as storing the whole distance matrix.

Then, lines connecting useful backbone nodes have to be created. At this point all the loads are connected to a graph containing cycles. A proper **in depth graph reading,** starting from one substation and turning back at another substation, permit to determine where the graph should be split in two feeders, by installing **normally opened switches.** The criterion for those switches location is to equilibrate the length per feeder. The resulting grid can be seen on the following figure.

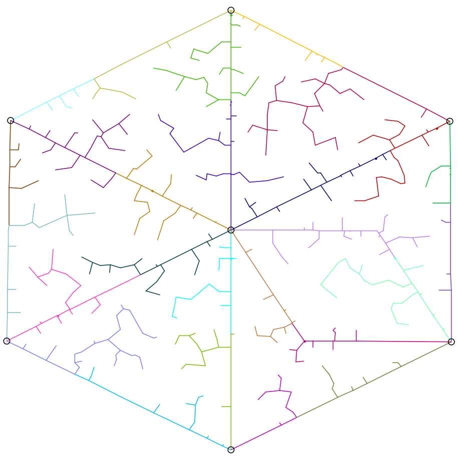


INCREASING THE NUMBER OF FEEDER

Adding new feeder is one traditional way to shorten too long feeders. The algorithm permits to make this kind of operation on the base grid previously defined. The chosen feeder that has to be split in two is the longest one.

Knowing the longest feeder permit to calculate its gravity centre, and the **two closest sides of the Delaunay triangle it belongs to.** Those two segments on which previous backbone were built are now split in two. The best solution in reducing length per feeder is kept.

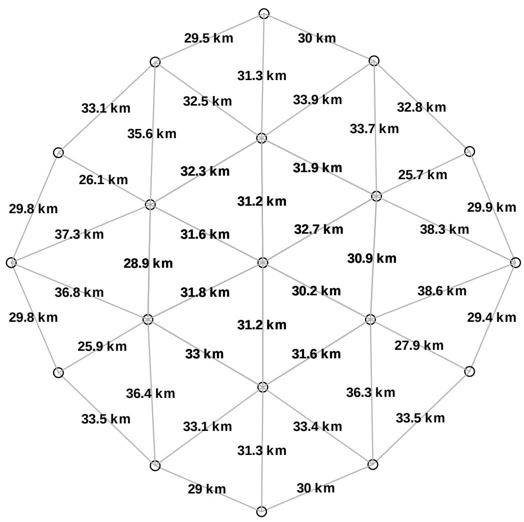
With a **proper rotation of the backbones**, as it can be seen on the following figure, new feeder can be added. The building of the grid is the same as detailed in previous section, using the modified backbones.



EXPLOITATION

It is possible to exploit this geometrical model to quantify the effect of territories and grid structuring on total grid length. The proposed calculation in this paper is applied on three different primary substation configurations, defining an area filled with loads until three given densities are set.

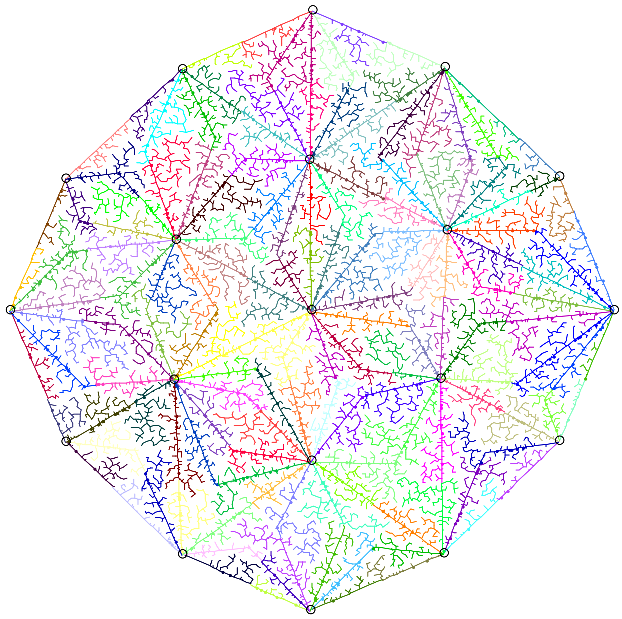
Substation density is built in a way that substations are separated by a **mean distance of 24, 32 and 40 km**, which are high (H), medium (M) and low (L). MV load densities are **0.5, 1 and 1.5 per square kilometre** (L, M and H), and they are separated by at least 400 meters. Substations configuration for a mean distance of 32 km can be observed on the figure below.



The nine configurations results in a number of loads, given by load density multiplied by the surface of the area. Those numbers of loads are summarized in the table below.

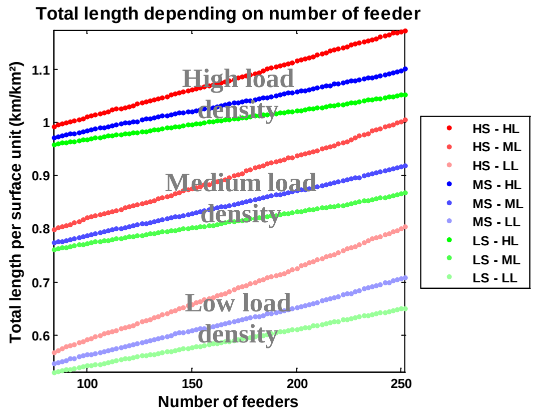
Loads / Sub-stations	H	M	L
H	8596	5236	2982
M	17192	10473	5965
L	25788	15709	8947

In this paper, focus lays on the effect of new feeder creation. At first 84 feeders supply the loads, for all nine configurations. New feeders are added, until numbers of feeders are multiplied by three, the total number of feeder is then 252. As an example, adding 30 new pairs of feeders on the medium density for load and substation would create the grid that can be observed on the following figure.

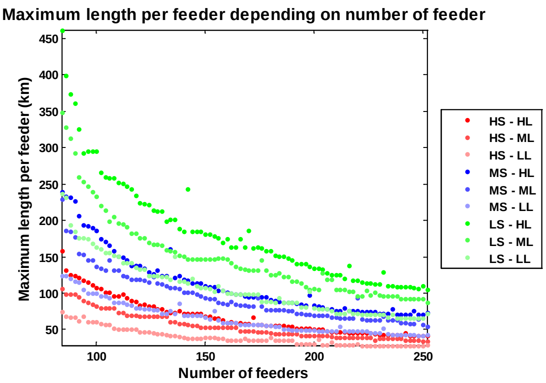


RESULTS

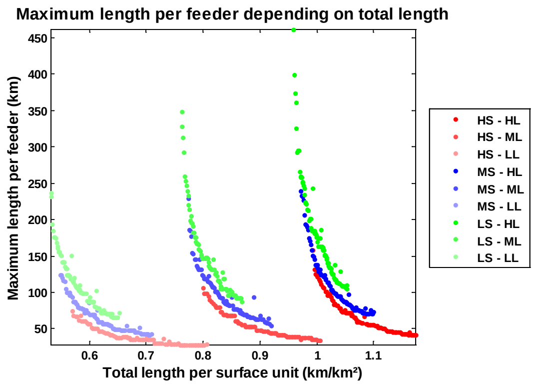
Results can be summarized on the curves below. HS – LL means high density of substation, with low density of load. The first curve shows the effect of creating new feeders on total length, for all nine configurations. One should notice that doubling the number of load has an effect of about 20% on grid length. Structuring the grid by introducing new substations and new feeders has also an effect of 20% for a given load density.



Structuring the grid increase total length, but gives the grid its capacity and its quality. Short feeders are supposed to have better properties for those essential characteristics. On the following figure, the effect of grid structuring on feeder length is drawn. Too long feeders can be shortened, and increasing the number of substations is not the only mean to do it. But there is a saturation effect: when the length of feeder is mainly due to backbone length, there is little effect of introducing new feeders.



Last figure shows the evolution of feeder length depending on total length. **First structuring actions are very profitable,** because feeder lengths are heavily reduced for a slight increase in total length.



CONCLUSIONS

MV Grid length is mostly due to load locations, and the distance between them. This paper proposes a method for automatic grid building, which underline **theoretical properties** of distribution network.

Following figures, according to [1] and [2], should be kept in mind when comparing distribution grids at a national scale.

Country	Population (Billion inhabitants)	Area (x1000 km²)	Population density (inhab/km²)
France (metr.)	62.8	550	114
Italy	60.6	300	202
Germany	82.3	360	229
Spain	46.1	500	92
Great Britain	58	230	252
Poland	38.3	310	124

Country	MV length (x1000 km)	MV length in km/cap	MV length in km/km²
France (metr.)	600	9.6	1.1
Italy	370	6.1	1.2
Germany	500	6.1	1.4
Spain	270	5.9	0.5
Great Britain	370	6.4	1.6
Poland	300	7.8	1

France is facing the most challenging territory characteristic in Europe, as one thousand inhabitants have to pay for 10 km of MV line, whatever the grid capacity might be. This is a **relevant factor to take into account when comparing national distribution grid performance indicators** (as SAIDI/SAIFI), or **grid development policy** (use of more expensive technologies such as underground).

According to the theoretical model, MV grid length is linked to the surface of dwelling areas. Denser countries benefits from naturally shorter grids, but it is also the case in some countries such as Spain, where wide areas are desert.

Beyond load density, its dispersion has an impact on grid length. Structuring the grid has also an impact on MV length, with the same order of magnitude. Structuring the grid has the main impact on energetic performance and capacity of the grid but it has relatively small impact on total length. As a consequence, it is impossible to have a proper idea of the performance and capacity of a grid if you consider only MV length. **But this is a relevant factor to compare the difficulty to supply a territory. Electrifying it implies an almost fixed cost.**

REFERENCES

[1] INSEE, 2010, *Population, superficies and densities of major countries of the world*

[2] 5th CEER benchmarking report on the quality of electricity supply 2011