



Bottom up calculation approach

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1 INTRODUCTION

The low voltage (LV) side of the grid has been undergoing a lot of changes in the recent years owing to the addition of Distributed Energy Resources (DERs) such as photo-voltaic (PV) panels, electric vehicle (EV) charging points for cars as well as heat pumps (HP). This ongoing effort for energy transition has impact on LV as well as the medium voltage (MV) and high voltage (HV) levels in the grid. The pressure experienced by the grids due to these constant additions at the LV side makes it important that reliable studies are performed on this end.

Since the LV grid is comprised of households, a detailed analysis about which DER's are present at each of them and what type of characteristics they exhibit needs to be studied. This is one of the reasons, bottom up approach has been implemented which provides a more reliable and customized picture of the LV network curating to the characteristics at every household.

Guide overview

The goal, reason and method for implementing the bottom up approach along with possible application scenarios are highlighted in this report.

2 WHY?

The need to predict the behavior of the power system due to the inclusion of DERs is of utmost importance for short as well as long term planning is of very high priority. It is no longer feasible and accurate to assume a constant growth percentage in network load as in the past for calculating the "What-if" cases. The need for consideration of specific details at the very end of the entire power system structure i.e., the households and its associated apparatus (EV chargers ,PV and HP) is important for prediction as well as estimation of the future scenarios. Accordingly, the required infrastructure adjustment in the grid should be done well in advance before running out of space for new connections.

The bottom up approach is a useful tool which considers the penetration of these DERs at the household level and gives a stochastic profile of what the cumulative loading is at the MV/LV transformer level. This information comes in handy for congestion analysis and a better idea of which section in the network needs to be immediately looked at while simulating future scenarios.

3 BOTTOM UP CALCULATION

As shown in Figure 1, a LV network (designed in Gaia LV Network design) is considered with plenty of household connections. Each of the households can consist of any number of apparatus like PV panels, EV charging station, electric cooking, heat pump along with the standard load which are modelled as Gaussian mixture distributions which is shown as an example on the right side in the form of probability distributions. As seen in the figure, PV is the only apparatus that generates electricity and hence it lies on the negative end of the x-axis which represents the power consumed by the apparatus against probability distribution on the y-axis.

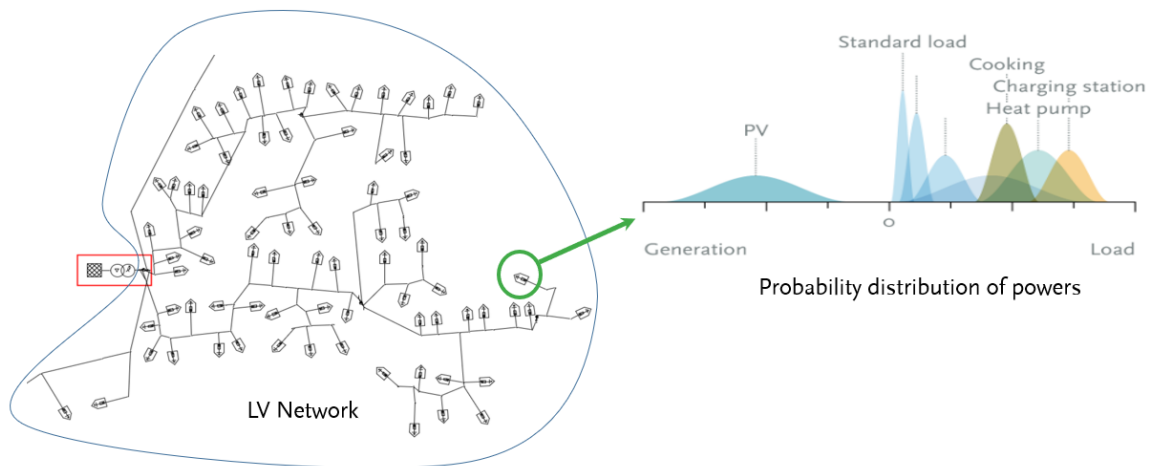


Figure 1 LV network with equivalent probability distributions of apparatus

For each of the households, depending on the apparatus present, Monte Carlo sampling is done for every quarter of an hour and the powers are added to obtain the possible equivalent power in each household individually for 200 sampling instances as shown in Figure 2. In this figure, the probability distributions of the standard yearly consumption and PV generation for a household is considered with a few sampling instances represented visually.

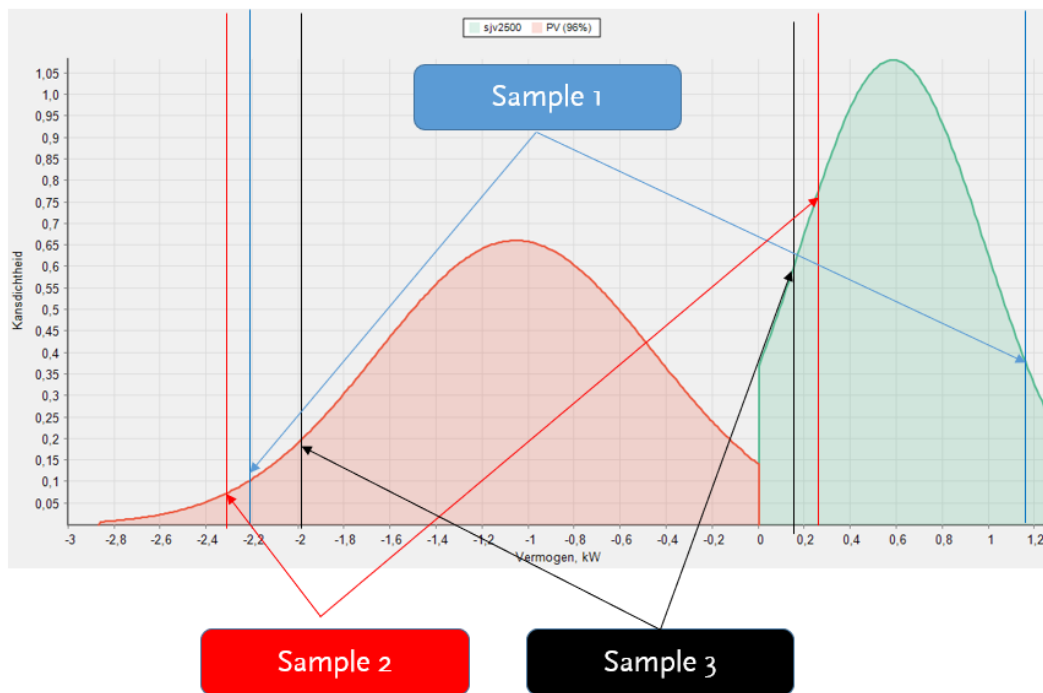


Figure 2 Monte Carlo sampling for apparatus in households

After this is done, the i^{th} sample for every household in the network is added up to get the equivalent power in the entire network (at the secondary side of the MV/LV transformer) and this is done for all the n sampling instances. The equivalent LV network is then a simple load as shown in Figure 3 with a range for the load distribution.

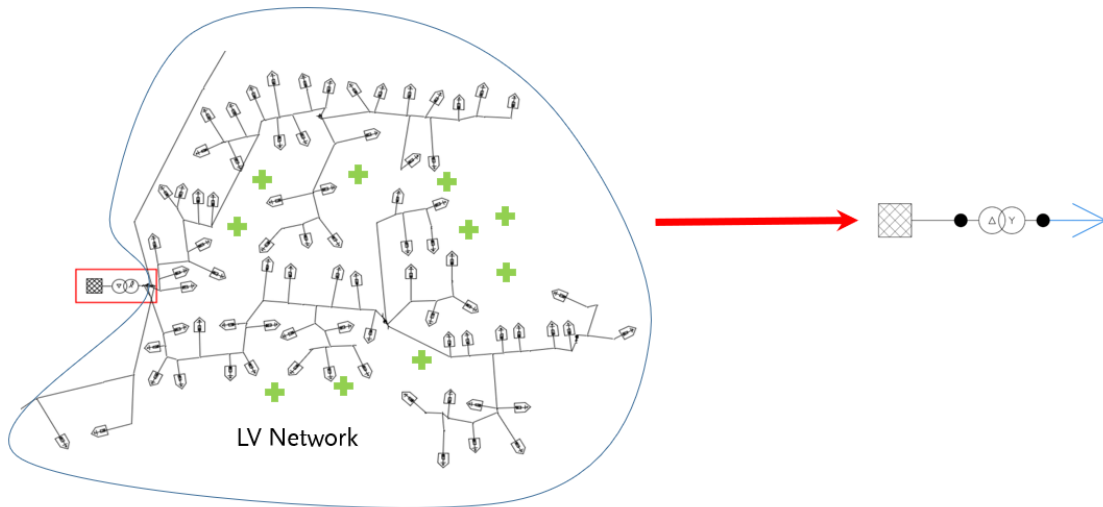


Figure 3 Equivalent LV Network

The final solution from the bottom up calculation is essentially a collection of n samples of active and reactive powers for each quarter of an hour of the day from which the mean (P mean, Q mean) and standard deviation (P std, Q std) is computed for every timestamp. After this, it is possible to get a range across which the values might vary. This range is roughly assumed to be mean ± 2*standard deviation. These are represented as shown in Figure 4 (all in kW and kvar). The output graph here corresponds to active power plotted against time but a similar analysis can be done for reactive power. The solution obtained from this calculation is stochastic and not deterministic one. For practical line of thought, the 95th percentile value can be assumed to be the most probable value.

Assumptions:

- Losses in the network are considered negligible and neglected.
- Network structure is considered to be radial, without parallel (meshed) operation of MV/LV transformers.

Time stamp 1	P mean 1	P std 1	Q mean 1	Q std 1
Time stamp 2	P mean 2	P std 2	Q mean 2	Q std 2
.
.
.
.
Time stamp n	P mean n	P std n	Q mean n	Q std n

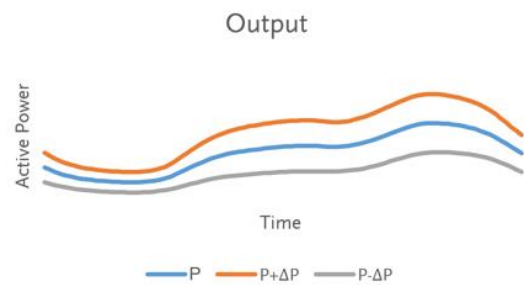


Figure 4 Equivalent Output

It is important to note that all the working days in a corresponding month are assumed to show similar behavior and the same holds for weekend days. Therefore, the results comprise of two days (working and weekend day) from each of the twelve months, with quarter of an hour intervals in each day. There are therefore 2304 [=2(types of days)*96(quarters in a day)*12(months in the year)] data points at the disposal of the user which covers all the days of the year.

Note: Since the results are statistically determined, the ideal situation is that the smart meter data lies in the range determined by the mean and standard deviation that is obtained from the bottom up calculations. This step will also help draw more conclusions on the assumption made regarding losses in the network and pave way for further modifications accordingly.

4 **PROOF OF CONCEPT**

Gaiacalc is a subset tool of Gaia which is used for batch calculations and other such operations. The initial implementation (proof of concept) has been done in Gaiacalc.

4.1 **Implementation in Gaiacalc**

The bottom up approach workflow is shown in Figure 5. Multiple LV network files (Gaia network file(.gnf)) can be selected with Gaiacalc for this calculation to be performed upon. The resulting outputs are Excel files that give the equivalent loads at the MV/LV transformers for each quarter of an hour. This profile data can be further used as inputs for MV/LV transformers state at every timestamp in distribution networks, and various operations can be performed. To perform this calculation, from the menu select **Batch -> Exporteren bottom up...** and then select the .gnf files on which the operation needs to be performed. The excel file containing the profiles are then generated individually for each network after the calculation is done.

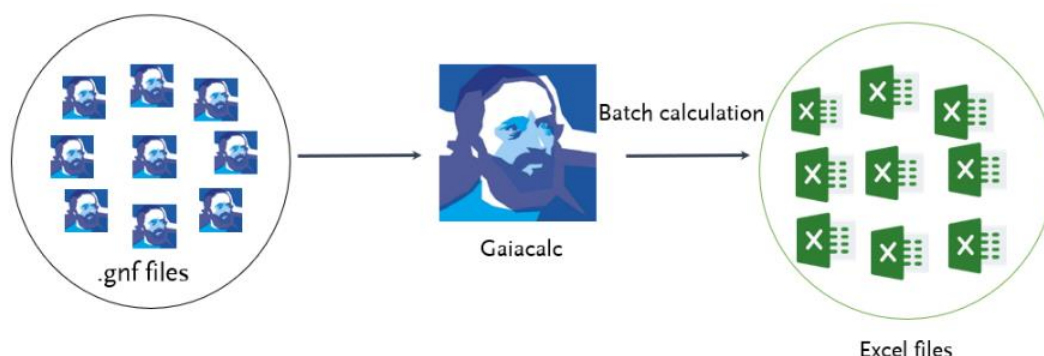


Figure 5 Bottom up approach (Proof of Concept)

4.2 **Output File Dissection**


On completing the bottom up computation, an Excel file (for every individual network) is the output with mean and standard deviations of the active and reactive powers of the equivalent load at the LV side of the corresponding transformers (if more than one is present) as shown in Figure 6. The units are in kW (for active power) and kvar (for reactive power) for the mean as well as the standard deviation (specified by _std in the units name). This represents the equivalent loading of the entire network at the secondary side of the MV/LV transformer.

	A	B	C	D	E
1	Datum & Tijd	Transformator	Transformator	Transformator	Transformator
2		kW	kvar	kW_std	kvar_std
3	15/01/2023 00:00	5,14019309	1,04376072	3,25699925	0,66136191
4	15/01/2023 00:15	4,82793128	0,98035326	3,14405803	0,63842821
5	15/01/2023 00:30	4,58105496	0,93022288	3,02723695	0,61470668

Figure 6 Output Excel file

5 IMPLEMENTATION IN GAIA LV NETWORK DESIGN

This functionality has been also added as a special calculation in Gaia. To use this, go to the **Bottom up** option from the **Special** section in the **Calculate** tab on the Gaia ribbon.

When clicked on the button , the calculation starts and at the end a window with an overview of apparent power is generated. Drop down menus to visualize the active and reactive powers as well as to select transformers in the network are available. There is also an option to export the results as a .xlsx file and another one to copy the graph at the bottom left of this window as shown in Figure 7.

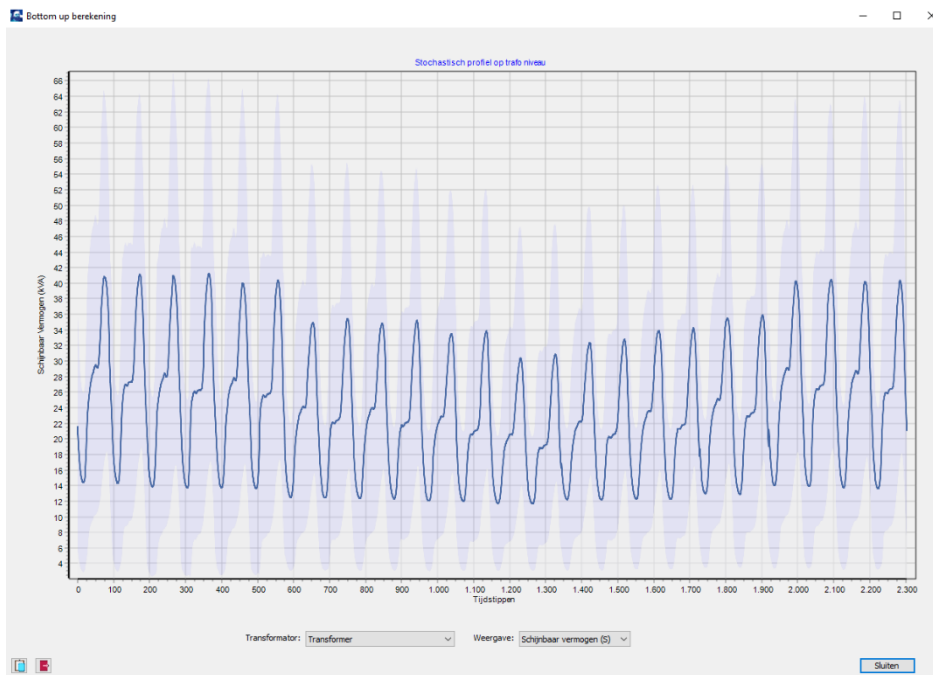


Figure 7 Pop up window with apparent power range from the calculation

The bottom up functionality can also be accessed from macro with the command **Bottomup()** and it saves the results in the form of a .csv file in the directory of the network on which the operation has been performed. This .csv file contents are similar to the one shown in Figure 6. A small example of the macro code that can be used for this functionality in Gaia is shown here.

```
// Working directory
Set(WorkingDir, 'Your directory here')

// Open GNF file
Set(GNF_with_Path, WorkingDir)
Add(GNF_with_Path, 'GNF filename.gnf')
OpenNetwork(GNF_with_Path)

// Command to run the calculation
Bottomup()
```

If a network is already open in Gaia, then the **Bottomup()** command can be used to generate a csv through macro or a graphical result as shown in Figure 7 can be generated using the option on the ribbon.

6 IMPLEMENTATION IN VISION CLOUD SOLUTION

The bottom up approach (Bottom up profile generation) is also integrated in Vision Cloud Solution (Vision CS). A profile (for active and reactive powers) is generated for workday and weekend day for each month (24 in total) and is displayed at the MV/LV transformer (MSR) in the Vision CS LS environment as shown in Figure 8. The display currently consists of the apparent power at the LV side of the transformer.

A unique strength of this feature is that it is the first step towards the linking of MV and LV levels. The calculated bottom up profile is also visible at the MV level mapped with the help of GIS-ID of the transformer.

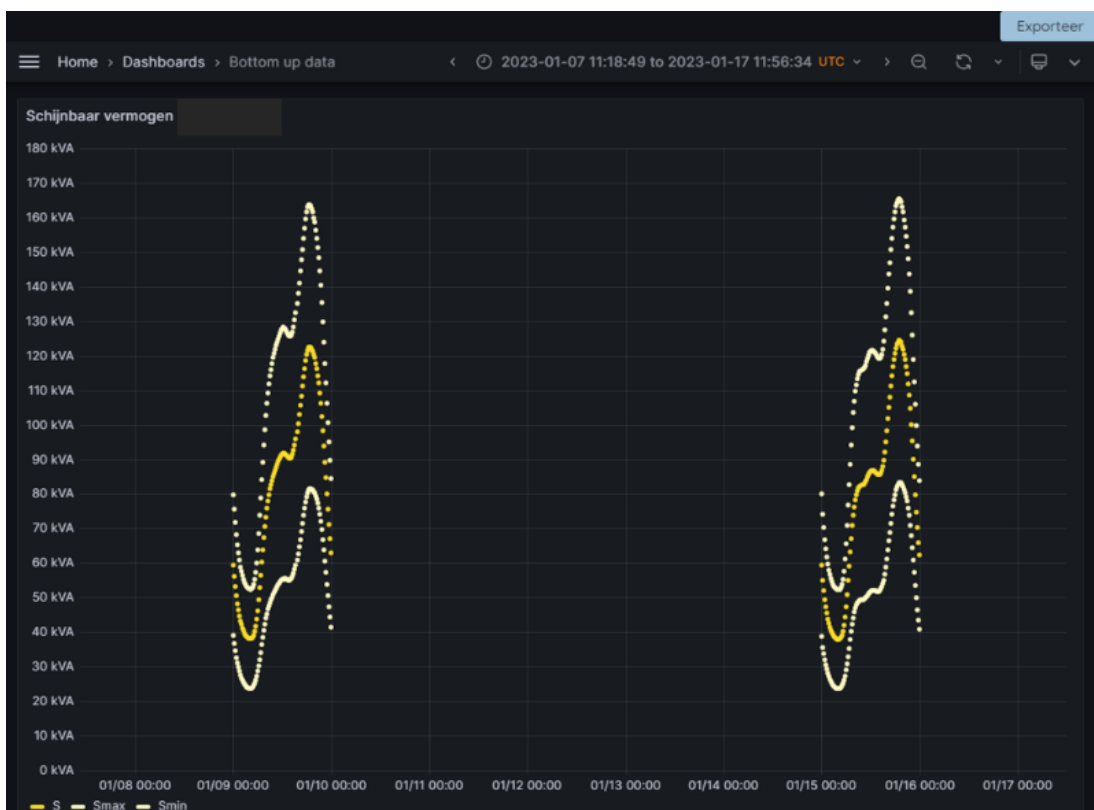


Figure 8 Vision CS Bottom up profile display

This data (95th percentile active and reactive powers) can be downloaded as a .xlsx format file and can be used further as a base in other profile calculations or as a foundation for further analysis using the “Exporteer” button on the top right in the figure below. A choice for the transformer (in case the network has more than one) also pops up when trying to export and after the choice is made, the Excel file with the data for that transformer (based on GIS-ID) is downloaded as shown in Figure 9.

	A	B	C
1	Datum & Tijd	trafo gis id	trafo gis id
2		kW	kvar
3	09/01/2023	74,82264	15,192865
4	09/01/2023 00:15	70,86594	14,39088
5	09/01/2023 00:30	67,10808	13,627605
6	09/01/2023 00:45	63,91095	12,978005
7	09/01/2023 01:00	61,09933	12,40592
8	09/01/2023 01:15	58,780245	11,936445
9	09/01/2023 01:30	56,863635	11,547065
10	09/01/2023 01:45	55,129635	11,19462
11	09/01/2023 02:00	53,81269	10,926915
12	09/01/2023 02:15	52,69603	10,70137

Figure 9 Exported 95th percentile values with corresponding transformer GIS-ID in the header

A significant feature here is that the transformers from the Vision CS MS environment can be cross referenced to the ones in Vision CS LS environment provided the GIS-ID of the transformer matches in both the cases.

This feature in Vision Cloud solution has upgrades/changes every release. For any new features, it is suggested to check the help tab in the application.

7 POTENTIAL APPLICATIONS

Few of the potential applications (to be noted that not all these are currently implemented in the products) are as follows:

- **Future scenarios:** The LV network can be modified according to the needs as well as expected changes in the grid to get a realistic overview and validation studies can be performed for the new scenario.
- **LV/MV coupling:** The profiles from bottom up computation serve as a first step towards linking the LV and the MV sides of the grid. This can help in overcoming the age old way of assuming a constant load/generation for the entire year by replacing it with a more dynamic and detailed profiles. Few of the sub-applications here are:
 - Load flow at peak load/peak generation instances: The extreme instances of the day/season/year can be selected at the MV network level and load flow studies can be performed as and when needed.
 - Profile load flow
 - Dynamic Contracts
 - Dynamic System Rating: Results of the profile calculation can be used as an input for estimating the thermal loading of components. Due to changing character of the profiles, thermal loading assessment typically introduces more capacity than tradition evaluation based on the nominal current.

- Data driven load flow / State Estimation
 - This is a module available in Vision Network Analysis ([the manual can be found via this link](#)) which has the capability to estimate the most probable state of the system based on available measurements.
 - These profiles can help to substitute missing measurement data and to obtain a more accurate estimate.
 - The bottom up approach in combination with Data driven load flow has the potential to help in dealing with planning and operational aspects of the Distribution System Operators (DSOs) considering the everchanging grid behavior.