GIS BASED AUTOMATIC GENERATION OF FUTURE ELECTRICITY PROFILES

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ABSTRACT

This paper describes a concept to automatically generate MV-LV transformer profiles from geometric and demographic GIS data. The load profiles are generated individually per location and time (regarding year, season and time of day) for a certain scenario and can be loaded into commonly used load flow software to assess the network assets. This paper describes the concept of the general model, the developed sub-models and a proof of concept.

INTRODUCTION

Since 1997 sustainable development has been a fundamental objective of the European Union [1] which is reflected e.g. in the European ten year growth strategy “Europe 2020” [2]. One of the objectives of this strategy is to reduce the amount of greenhouse gas emissions in the year 2020 with 20% with respect to those of 1990. More than 50% of these gasses are emitted by the Transport and Energy supply sector [3]. For the transport sector, electric vehicles (EV) are seen as a solution to achieve emission reduction. For the energy supply sector, electricity generation from renewable energy sources (RES) such as photovoltaic generation (PV) and wind energy, and energy-efficient conversion by combined heat and power (CHP) plants are regarded as promising technologies. Therefore, member states, such as the Netherlands, have set long-term development goals as can be seen in TABLE 1 and 2.

TABLE 1: Dutch ambitions on EV [4].

Year	Number of EV
2015	20,000
2020	200,000
2025	1,000,000

TABLE 2: Dutch ambitions on RES [5].

Goals for 2020
20% RES of the energy supply
6 GW installed wind power at sea
2 GW installed wind power at land
0.5M houses have PV or CHP installed

The realization of these goals will affect the entire power system, with most changes happening at the level of distribution grids since new loads and generation technologies have to be accommodated: plug-in EVs travelling to different locations depending on the time of day, and renewable energy sources such as PV and wind generation with fluctuating output [6]. Therefore, traditional network planning based on extrapolation of historical data, such as economic growth, is no longer sufficient [7]. As a result, distribution system operators (DSOs) will have to develop new planning strategies. As an essential input to planning strategies, the future loads and generation profiles must be estimated, since these will differ per location and over time [7-8]. For instance, EV and RES profiles differ locally, depending on variables as customer behaviour, urbanization level, size and type of buildings, and income per household.

This paper focusses on a method to automatically generate future power profiles for MV-LV transformers in a distribution grid. These profiles are based on publically available geographical information from a geographic information system (GIS) for the load flow program Vision. A program used by the majority of the Dutch DSOs for network planning.

First, the general concept of the model is explained. Secondly, the several sub-models are explained in more detail. And finally the concept is applied to an existing MV network in the Netherlands.

CONCEPT OF THE MODEL

This section will describe the data used by the model, as well as the general concept and the implementation of the model. The model has two data sources: A network file containing information of the network and a database containing information of every location in the Netherlands. These sources will be discussed first, before elaborating further on the general model.

Data sources

The model is built around the load flow program Vision by PhasetoPhase which is commonly used by the DSOs in the Netherlands. Network files for this program are generated automatically from data of the DNO’s GIS system and do not only contain electrical data of components, but also contain geometric information of the components. With this data, the network can also be shown geographically in the complementary program called Grid Navigator by PhasetoPhase.

Figure 1: Different visualisations of a MV network.

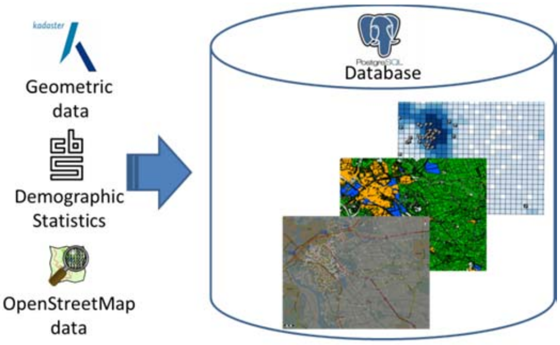

Figure 2: Concept of the PostgreSQL database.

In Figure 1 the classical one wire representation in Vision of a MV network is shown, while on the right inset the same network is shown geographically.The network files are used as input for the model. Besides the geometric information of the assets in the network file, other geometric information is used as well. This information is stored in a PostgreSQL database as depicted in Figure 2. The PostgreSQL database is equipped with the PostGIS extension which makes it suitable for databases with geometric information. The database is filled with (geometric) information of all buildings in the Netherlands from the Dutch Cadastre [9], demographic statistics of the whole Netherlands provided by the Dutch Central Bureau of Statistics (CBS), and geographic information from OpenStreetMap.

Besides geometric datasets, other information is needed to generate future profiles. Information of national future scenarios (such as the share of EVs, the penetration of PV) is extracted from [7]. To simulate PV generation a dataset of ten minute values of measured irradiation and temperature over a period of ten years from several weather stations of the Royal Dutch Meteorological Institute (KNMI) is used. The Dutch national mobility survey (OViN) [10] is the basis to sample driving behavior for the EVs. A dataset of standard profiles from ESDN [11] is the input to generate household profiles.

General Model

The general scheme of the model can be found in Figure 3. The model is implemented in a Matlab environment where a network file is imported and analysed. The MV-LV transformers are identified and their service area is determined. Depending on the desired year and scenario information of penetration levels of several technologies are is gathered. The model extracts extra information of the transformers service area, such as the numbers of residences, from the PosgreSQL database. Per technology a sub-model processes this information to form new load profiles. These are then aggregated per transformer en the result is written into an Excel file which can be used as input for Vision to perform load flows.

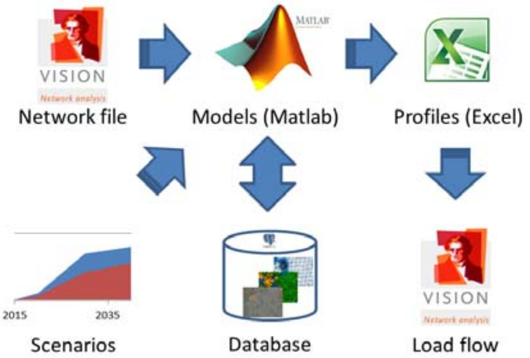

Figure 3: Basic steps of general model.

Within the Matlab simulation environment there are four main steps: First, the network file is parsed and the scenario data is loaded to determine the size of the simulation model that has to be build and link parts of the simulation model to the network file. Secondly, the simulation model itself is build (initialisation of the model). Thirdly, a simulation of the model is done, to, finally, collect the resulting profiles per transformer and write them in an Excel.

Determining the size of the simulation model

The location of the MV-LV transformers is used to determine the area that has to be assessed by the simulation model. This area is the service area per transformer, but all that is known is the location of the transformer itself. To determine the service area the whole area covering the Netherlands is divided in hectares (similar as the lower layer depicted in the database in Figure 2). Furthermore the Netherlands is divided in neighborhoods by the Dutch Cadastre. Hectares of all neighborhoods covering one or more transformers are selected and regarded as the service are of the whole MV network. The neighborhoods were generally built one by one. Therefore, it is assumed that a MV-LV transformer will service only hectares within the neighbourhood.

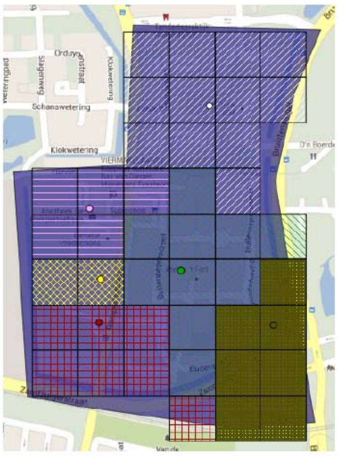

Figure 4: Hectares linked to a transformer.

The hectare is than linked to a the transformer that has the highest value for L, where L is the ratio between the yearly maximum loading of the transformer and the squared value of the distance between the transformer and the hectare. Figure 4 depicts a neighbourhood with transformers (dots) and the linked hectares (shaded squares). Now the hectares can be linked to a transformer of the network file and one knows which hectares have to be assessed.

Initialisation

The following step is to initialize the model that will be simulated. Object oriented programming within Matlab was used to define classes for the blocks depicted in Figure 5. The classes are used to define objects. The 'Data' object contains a direct connection to the PostgreSQL database, but also contains the datasets described earlier. All objects inherit the properties of the handle class defined in Matlab. This reduces the required memory space significantly. Using handle based objects instead of value based objects, it is possible to make double linked structure. This means for instance that a 'Building' object has a handle for the square it belongs to, and the corresponding square has a handle for the building as well. Furthermore, every object has a handle directly to the 'Data' object. The 'Region of interest' object is created and incorporates the 'Data' object as well as the list of squares for the grid. At initialisation of the 'Region of interest' object, a 'Hectare' object is created for every hectare of the list. When a 'Hectare' object is created, it retrieves data of the hectare from the PostgreSQL database. When there are buildings present, a 'Building' object is created with the characteristics such as roof area and the number of residences. Probabilistically is determined from the scenario data, the presence of a PV module. Accordingly, related to the roof area, a 'PV module' object is created.

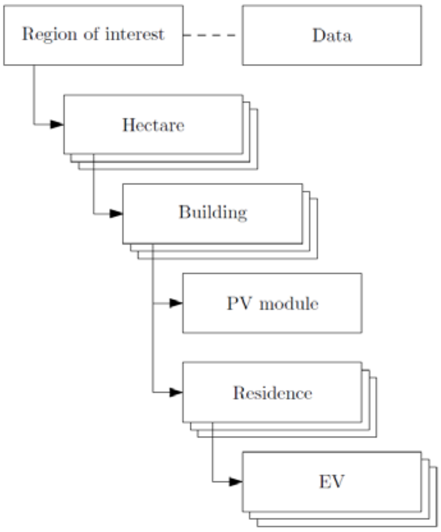

Figure 5: Initialisation of the simulation model.

The correct number of 'Residence' (household) objects is consequently created and, depending on the scenario and average number of cars per household, a number of 'EV' objects is created.

This framework of class based objects enables expansion of the model. Additional technologies such as heat pumps could be implemented, but also improved sub-models can easily replace the existing ones. The classes could even be implemented with an additional controller object to implement the controlled charging of vehicles.

Simulation of the model

In this step the model is simulated for one or multiple days. The 'EV', 'PV module' and 'Residence' objects will determine their individual profiles according to their corresponding sub-models which will be described further on in the paper. These profiles are than aggregated per hectare in the 'Region of interest' object.

Collecting simulation results

The final step is to collect all the hectare profiles per transformer and sum them together. The result is the future transformer load profile. This profile is then written into an Excel file which will act as input for the load flow software.

SUB-MODELS FOR LOAD PROFILES

This section will elaborate on the three main sub-models used for generation of the Household, PV and EV profile.

Household load profile

The profile of the household load is based on data from ESDN. This data is normally used in the Netherlands to allocate power flows and to estimate the required capacity of assets. Multiplying the yearly electricity use of a household with the fractions of the ESDN dataset results in a smoothed profile for that household. Although this profile is an average profile and therefore far to smooth for a single household, it is assumed that after aggregation on the MV-LV level this effect will be negligible. The average electricity use of a household per residence is extracted from the PostgreSQl database. Future work regarding the model will consist of a more detailed sub-model for household loads.

PV generation profile

The PV sub-model consists of two parts: One part determines the installed peak power on a building. The other translates the peak power, weather variables and time into a power profile.

To determine the peak power of a PV installation on a residence building the function and footprint of the building is used form the Dutch Cadastre. There are two different sub-models developed for determining the peak power of an installation; one for single household

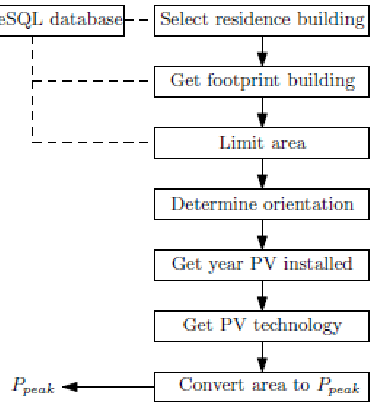

Figure 6: The model for the determination of the peak power of a PV installation.

buildings and another for the remaining buildings. Figure 6 shows the model for buildings that only have one function which is being a residence for one household.

First building is selected that fulfils the aforementioned criteria. Secondly, the footprint of the building is determined as shown in Figure 7. Only one third of the tilted roof is assumed to be suitable due to chimneys and windows, and the two roof sides. Also the orientation can reduce the effective PV panel area. From the scenarios the installation year of a panel is determined (if it is installed at all). Depending on the year of installation and the technology (mono- or polycrystalline), the peak power is determined. The peak power is used as input for the PV profile model depicted in Figure 8. Another input is the time, since the generated power is dependent on the season and the time of day. The day of the year is determined and from one of the ten years of weather data, a day of the year nearby is sampled.

Figure 7: Footprints of single residence buildings.

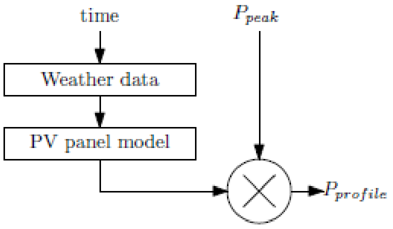

Figure 8: Schematic of the PV profile model.

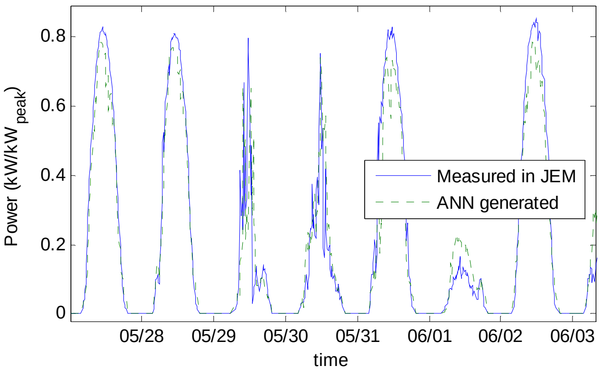

Figure 9: The PV panel power per kW$_{peak}$ installed.

Since the efficiency of a panel also depends on the temperature this is also sampled from the dataset [12]. These variables act as input for an Artificial Neural Network (ANN) that maps the solar irradiation to a power output. Because the KNMI measured the irradiation on a surface perpendicular to the zenith and the sun moves along the horizon during the day and the year, the time of the day and the day of the year are also inputs for this ANN. The ANN was trained with measurement data of a full year from the smart grid JEM pilot in the Netherlands consisting of around hundred houses with PV panels.

EV load profile

The EV load profiles are based on the Dutch OViN mobility survey. This survey includes a dataset with more than 127.000 movements of Dutch people. From the dataset movements by passenger cars are selected and the total daily driven distance is determined as well as the arrival time at home at the end of the day. The driving behaviour of Dutch citizens is related to income and urbanisation level [13]. The dataset is, therefore, split up in fifteen subsets according to standardised household income (three classes) and urbanisation level (five classes) as defined by the CBS. Also the workdays and weekend days were split. The correct subset is selected depending on the demographics of the house of the EV owner. The daily driven distance is than converted to the energy to charge by the EV. A value of 4-6 km/kWh is used depending on the time of the year. Finally, a profile is generated for each EV, which would charge the required energy with 3.7 kW [6] from the moment of arrival at home.

PROOF OF CONCEPT

The developed concept for automatic generation of MV-LV transformer profiles was implemented and simulated on a network file of an existing MV network. The concept enables the production of profiles of every available MV network file of the Netherlands. For the proof of this concept an extreme scenario was chosen for the year 2030 with 5.8 GW$_{peak}$ PV installed and 1.75

Figure 10: The MV network with an extreme scenario in 2030 at 19:30 hour.

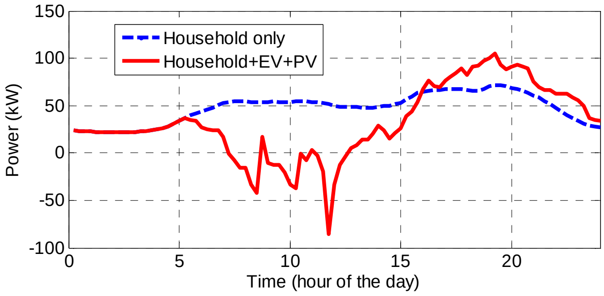

Figure 11: A generated power profile for a transformer for an extreme 2030 scenario..

M. EVs in the Netherlands (Scenario C in [7]). The result displayed in Grid Navigator can be seen in Figure 10, were red bars indicate overloaded MV-LV transformers and red lines indicate overloaded underground MV cables. A future profile can be seen in Figure 11. It is clear to see the impact of PV during the day, which results in a net in feed of power from the LV network into the MV network. Also the extra peak in the evening from charging the EVs is clearly noticeable.

CONCLUSIONS AND FUTURE WORK

The proposed concept seems to generate appropriate profiles for the MV-LV transformers. The approach enables load profile generate for every location in the Netherlands. The object oriented approach lends itself for future additions and improvements of sub-models. One might think of adding heat pumps or wind turbines as an extra technology, or the implementation of controlled charging for peak shaving or improving the facilitation of RES. Future work will furthermore focus on the evaluation of the simulation results of the load flow software for the purpose of network planning.

ACKNOLEDGEMENT

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