CAPACITY MANAGEMENT OF LOW VOLTAGE GRIDS USING UNIVERSAL SMART ENERGY FRAMEWORK

Edward COSTER, Stedin – Netherlands, edward.coster@stedin.net
Henk FIDDER, Stedin – Netherlands, henk.fidder@stedin.net
Milo BROEKMANS, Stedin – Netherlands, milo.broekmans@stedin.net
Christian KOEHLER, Venios - Germany, christian.koehler@venios.de

ABSTRACT

It is to be expected that the number of electric vehicles will be growing in the near past. This can lead to serious grid congestion in low voltage grids and massive investments in solving this congestion. In this paper capacity management of low voltage networks is studied with the aid of a Universal Smart Energy Framework. With this framework grid congestion is solved via flexibility of loads and generation. The framework is applied in a pilot project in a neighbourhood of the city of Utrecht. This paper gives an overview of the framework, a description and goal of the pilot project as well as some preliminary results.

INTRODUCTION

The traditional energy sector is changing. In the past electrical energy was generated in bulk by large centralized power plants while the trend is now to generate electricity with small distributed generation units, for instance Photo Voltaic (PV) systems. Besides a change at the generation side there is also a change at the demand side, for instance, an alternative way for space heating by applying heat pumps. Another major development to be expected is the Electric Vehicle (EV) which will be replacing the fossil fueled cars in the future. These trends are ongoing and can have a significant impact on especially electricity distribution grids. As a DSO Stedin has to be prepared for the upcoming energy transition and adapt their grid design policies in such a way that this transition can be managed cost effectively and with a minimum of nuisance for their customers.

Integrating new types of systems, such as heat pumps, electric vehicles, battery storage systems and PV systems, lead to a different usage of the electricity grid with less predictable energy flows. There are many examples of LV grids who have an excessive integration of PV systems which lead to an export of electric energy towards the Medium Voltage (MV) grid in the afternoon exceeding the energy consumption in the evening. The new usage of LV grids have not been foreseen in the initial design of these grids and can lead to serious bottlenecks and large investments solving these bottlenecks.

Traditionally, grid reinforcements are the solution for bottlenecks however, new solutions are under development using flexibility in both energy demand and supply. Examples of solutions using customers' flexibility are given in [4] where Demand Response (DR) is used to affect customers' energy consumption applying price incentives as well as deployment of storage systems (batteries and hot water tanks) to cope with local fluctuation due to significant PV activity.

Stedin participated in the development of the Universal Smart Energy Framework (USEF) which can be considered as a transactive energy system. The goal of the USEF framework is solving grid congestion using the flexibility properties certain loads and energy source possess, such as shifting the charging of EV, storing PV power in local batteries, switching on (or off) heat pumps or ultimately curtailing PV generation (if other solutions will not work).

The focus of this paper is on the application of USEF in a pilot project involving EV charging via PV-systems. The integration of the charging poles and the PV-systems in an existing LV grids dated from the mid-fifties can lead to grid congestion. For Stedin the goal is to solve the grid congestion via the USEF framework and prevent traditional grid reinforcements where possible.

LOMBOK PILOT PROJECT

Recently with several partners Stedin has started a pilot project. In the pilot project the focus is on electric vehicle charging by solar power as much as possible. First part of the project consists of installing twenty charging poles in the Lombok neighbourhood of the city of Utrecht. These charging poles are used by residents who owns an EV and voluntary take part to the project. Besides the charging poles also PV systems are installed. These systems are mainly installed on public rooftops such as schools, for instance.

The final goal of the project is to create a neighbourhood energy system where EV is charged by PV-systems when there is a surplus of PV-power but also discharge the cars via Vehicle To Grid (V2G) charging poles when there is a power shortage. All installed charging poles in the pilot project have the capability for V2G.

Also a part of the project is *We Drive Solar* initiative. This initiative covers future need for mobility and consists of electric pool cars. These pool cars can be used by local residence which via a membership. The first 150 cars will be delivered in 2017 for the city of Utrecht and a part of these cars will be located in the neighbourhood of Lombok. A distinctive feature of this initiative is that these cars are also part of the neighbourhood energy system where the cars are used for local balancing of the power flow.

Figure 1: *Electric Vehicle of the We Drive Solar Initiative*

This means that generation peaks due to PV-systems are covered but also to solve grid congestion by offering flexibility during charging and V2G possibilities in times of a shortage of power. In figure 1 one of the first electric vehicles of the *We Drive Solar Initiative* is shown.

UNIVERSAL SMART ENERGY FRAME WORK

As mentioned in the introduction the traditional solution to solve grid congestions is reinforcing the grid with extra cables. Because of the expected increase in bottlenecks in the LV-grid due to the energy transition this method is cost intensive and other solutions, based on unleashing flexibility, are under development. A solution which offers demand side flexibility is USEF.

Prosumers

Up to this moment the majority of household electric energy consumption occurs in a passive way. However, more and more consumers become active due to installation of PV and battery storage systems. These customers become prosumers which are customers who not only consuming electric energy but producing it as well. This prosumer becomes more flexible in his energy demand and supply [1].

Aggregator

The energy consumption of household appliances are such that the amount of flexibility which can be provided by the prosumers is not sufficient to contribute to load balancing or relief in grid congestion. Therefore, aggregated flexibility is needed. This requires a role that is collecting the available flexibility of a group of prosumers and aggregates it to a larger volume of flexibility. This role is the aggregator role. Collecting prosumers' flexibility and making it available to other roles require clear processes, responsibilities and message descriptions [1]. That is what USEF is about.

Central position in USEF is taken by the aggregator. The aggregator is responsible for acquiring flexibility from prosumers, aggregating it in a portfolio, and offering this flexibility services to different markets and market players. For the aggregator four possible different market players are distinguished [2]:

1. The Prosumer
2. The Distribution System Operator (DSO)
3. The Balance Responsible Party (BRP)
4. The Transmission System Operator (TSO)

In this paper the focus is on the prosumer and the DSO. More information on other market players can be found in [2]. The general USEF value chain is given in figure 2 and it can be clearly seen that the aggregator has the central position in the framework [3].

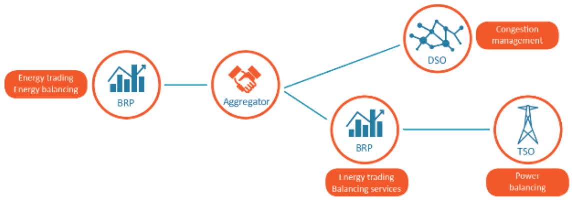

Figure 2: General USEF value chain [3]

USEF IMPLEMENTATION IN LOMBOK PILOT PROJECT

General USEF PROCESS

As discussed in the previous sections in this pilot project grid congestion will be solved via demand side flexibility as much as possible. In the USEF framework various roles are described however in this pilot project the most important roles are the aggregator role and the DSO role. In figure 3 a flowchart of the general USEF process is depicted. This flowchart shows the interaction between the aggregator, DSO and the USEF framework.

The process starts with a day-ahead load forecast provided by the aggregator. This is a prognosis based on 96 Program time Units (PTU, 15 min values) and covers the loads and generation which are represented by the aggregator. This forecast will be sent to USEF who will forward this message to the DSO.

After receiving the aggregators' load forecast the DSO completes the load data which is not represented by an aggregator and performs a grid safety analysis. In the grid safety analysis for all predefined congestion points the expected loading is determined for all 96 PTU values. In case of no grid congestion USEF will be informed by the DSO and USEF sends a message to the aggregator that no grid congestion will be expected hence the aggregator can proceed as scheduled.

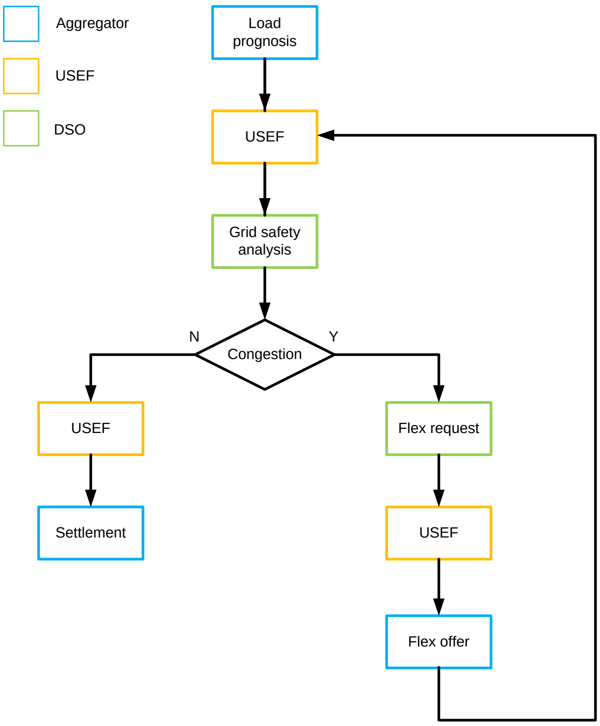

Figure 3 : *Flow chart of general USEF process*

Because per congestion point the available grid capacity is known, it can also be determined how much flexibility is needed to relieve the grid and solve the grid congestion. Therefore, in case of congestion a flex-request is sent out to USEF which is forwarded to the aggregator. The aggregator responds with a flex-offer and via USEF the grid safety analysis is repeated to check if the flex-offer is sufficient to solve the congestion. If this is the case a settlement procedure follows and the flex offer is ordered. In the future it is expected that multiple aggregators are active which can offer flexibility for certain grid congestion and then a market place is established where the best fitting flex-offer(s) will be ordered.

Implementation of the USEF framework

In the pilot project the charging poles are operated by the Charge Spot Operator (CPO) which has the ability to control the charging process of EV. However, the charging poles are managed by an aggregator. The aggregator has implemented their part of the USEF framework in software to be able to provide the day-ahead forecast of all charging poles of the pilot project. Via the software the aggregator is also able to handle flex offers and orders.

For the grid safety analysis, the loads and generation not represented by the aggregator has to be estimated. This will be done in the Venios Energy Solution (VES) platform. In this platform a model of the involved LV-grids is implemented. The loads are forecasted based on predefined load profiles which are tuned via measurement data obtained from the LV-side of the distribution transformer and LV-feeder measurements. Details of the load forecast as well as the grid safety analysis will be given in the next section.

In figure 4 an overview of a part of a secondary substation, the low voltage switchgear, is shown. On the wall a cabinet is mounted in which the measurement devices are housed. The measurement devices measure all electric quantities (P,Q I, V, p.f. kWh, kVArh) as well as Power Quality phenomena.

To check the proper execution of the flex orders all charging poles are individually measured. These measurements are also used for near real-time monitoring of the LV-grids. This near real-time monitoring is also performed in the VES platform.

Figure 4 : *Low voltage switchgear and measurement cabinet*

GRID SAFETY ANALYSIS (GSA)

The intervention in the grid operation in order to control the load flow and to maintain the predetermined power quality requires the knowledge of the state of the electrical network. The best information on the power supply is obtained by installing measurement technology at all nodes in the network. Since this is not useful for economic reasons and it was not necessary in the past, only a few real-time measurements are available on the distribution network. Therefore, state estimation methods, which are necessary based on measured values in a few locations and a network model which determine the most probable state in the entire network, are necessary. At the level of the transmission networks, state estimation has been state of the art since the 1970s.

Distribution networks, however, differ, among other things. In their topology, the R / X ratio, the often unbalanced load and the high number of network nodes, differs strongly from the transmission networks. Furthermore, the state estimation methods in the transmission network serve to validate the measured values in a fully or over-determined system, while state estimation methods in the distribution network serve the replacement of measured values in a subordinate system. Processes for assessing the state of transmission networks cannot be transferred directly to the distribution network. In addition, many monitoring and control systems of the distribution network operators are not very high-tech. Procedures that already exist today usually can not specify a unique network state. You can only limit the solution space for the state of the network [4-5].

Hybrid approaches form a corresponding alternative. In this case, the grid is initially imaged and simulated as complete as possible with its feeders and consumers. The core of the simulation is formed by dynamic load and feed-in models, which partly access external data sources, as well as the concrete network topology. The state estimation is enriched by a limited amount of real measurement values which deliver a backward correction of the model results. The electrical network is divided into individual hierarchical measurement areas as a function of the topology. Measurement areas are generated whenever one or more measuring sensors delimit one or more network strings from the rest of the network [6]. The correction is made on the basis of the model results, in contrast to older approaches which carry out a linear or worst-case distribution [7].

The grid safety analysis (GSA) combines a pure simulation and the results of the state estimation. The dynamic load and feed-in models are continuously tuned by real measurements and by the results of the state estimation. Currently the tuning is integrated as an observed process. The simulation results are analyzed with regard to the transformer capacity, size of the fuses and the line parameters. A depth search approach also checks the load properties in dependence of the load direction. Necessary load reductions are then calculated per congestion point.
The analysis also included the calculation of free capacities if the grid is within the defined safety range.

PRELIMINARY RESULTS

In this section some preliminary results are shown. These results focus on the aggregators' D-prognosis and the grid safety analysis. According to figure 3 the USEF process starts with an initial D-prognosis of the charging poles for each congestion point (CP) sent by the aggregator. An example is given for a secondary substation where the CP's are shown in figure 5.

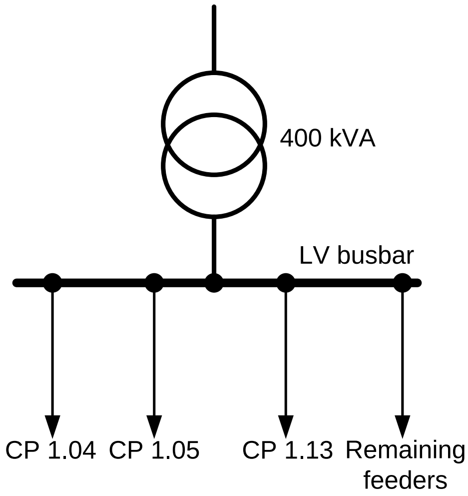

Figure 5: *Secondary substation layout including congestion points*

In figure 5 the indicated CP's are the feeders in the pilot project where the charging poles are connected to. The goal of the pilot project is to reduce congestion by using the charging poles as flex sources.

In the example given below transformer congestion is investigated. Figure 6 gives, amongst others, the D-prognosis of CP 1.13. Furthermore, the D-prognosis of the other CP's as well as an estimation of the remaining load is used to determine the expected transformer load (yellow). The blue dotted line indicate the remaining room at CP 1.13. This is done by an equal distribution of the remaining transformer capacity ($(C_{tr}-P_{tr})/\#CP$). In this example the number of congestion points is 3 hence the blue line indicates 33% of the remaining transformer capacity. A remark is when the feeder itself has a smaller available capacity due to own feeder loading. In that case the remaining capacity of the feeder is shown.

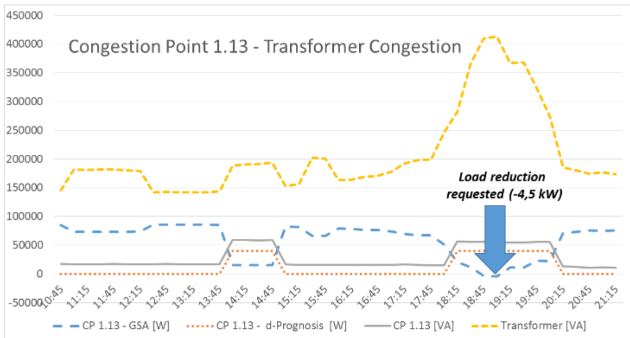

Figure 6 : *A congestion occurs due to the overload prediction of the transformer (yellow). The GSA requests a load reduction by 4,5kW (blue).*

In figure 7 the D-prognosis of CP 1.04 and 1.05 are given and the results of the analysis incorporating all CP's are depicted. For all congestion points via a GSA the remaining capacity is calculated.

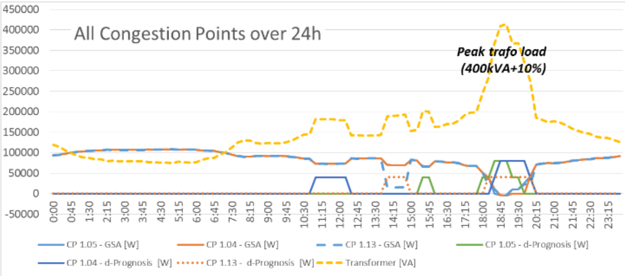

Figure 7 : *The effect of all congestion all congestion points d-Prognosis is clearly visible in the transformer load prediction (orange) by the GSA.*

The result of the GSA is that transformer congestion occurs for some PTU's hence for these PTU's the charging power has to be reduced. Total congestion is about 13,5 kW which means that every CP has to reduce the charging power by 4,5 kW as indicated in figure 6. As discussed in section and depicted in figure 2 the next step is to send a flex request to the aggregator. These next steps will not be further discussed in detail.

The whole system is currently in evaluation during the real field operation. Figure 8 shows an exemplary result from the user interface. The system operation can be supervised from this dashboard.

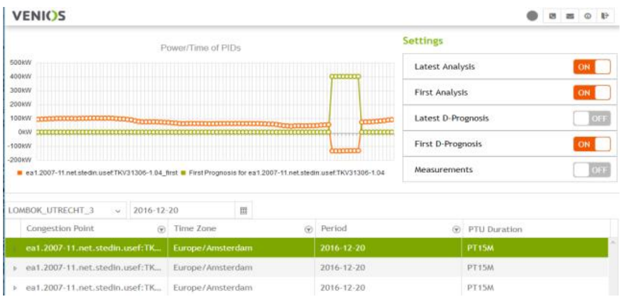

Figure 8 : *System screenshot (USEF dashboard) with GSA result (orange) and d-prognosis (green)*

With the aid of the dashboard and the measurements per CP it can be determined if the ordered flexibility is delivered by the aggregator.

CONCLUSIONS

In this paper capacity management of low voltage networks using flexibility of EV charging is discussed. The flexibility is unleashed via the USEF framework which is applied in a pilot project in the Lombok neighbourhood of the city of Utrecht. A description of the pilot project as well as some preliminary results of key elements of the USEF process are given.

The current results are showing that the capacity management by USEF is working. Nevertheless, the long-time field operation will deliver additional results regarding the quality of the predictions and user experience due the temporal capacity limitations.
In addition, the extension of the USEF framework is discussed. This includes the explicit handling of reactive power and the introduction of hierarchical or dynamical congestion points.

REFERENCES

[1] M. van den Berge, M. Broekmans et al, 2016, "Flexibility provision in the Smart Grid era using USEF and OS4ES", in *proc. IEEE international Energy Conference (ENERGYCON)*

[2] R. van Gerwen, H. de Heer, "USEF position paper: Flexibility Value Chain", www.usef.info. October 2015

[3] M. van der Laan, "USEF position paper: Electric Mobility", www.usef.info. October 2015

[4] B. Merkt, Beitrag zur Zustandsidentifikation von elektrischen Energieversorgungsnetzen. *Berichte aus der Elektrotechnik.* Shaker, 2008. ISBN : 9783832272289.

[5] M. Wolter, Grid State Identification of Distribution Grids. *Berichte aus der Elektrotechnik*. Shaker, 2008. ISBN : 9783832275464.

[6] C. Albrecht, Entwicklung einer skalierbaren Netzberechnungskomponente für ein Cloud-basiertes Monitoringsystem für Smart Grids, 2014, Ruhr Universität Bochum

[7] N. Neusel-Lange. Dezentrale Zustandsüberwachung für intelligente Niederspannungsnetze: Neue Energie aus Wuppertal. Bd. 1. epubli GmbH, 2013.