INTEGRATING SMART STORAGE AND AGGREGATORS FOR NETWORK CONGESTION MANAGEMENT & VOLTAGE SUPPORT IN A PILOT PROJECT IN EINDHOVEN

Sharmistha BHATTACHARYYA
Enexis – The Netherlands
sharmistha.bhattacharyya@enexis.nl

Ton VAN CUIJK
Enexis – The Netherlands
ton.van.cuijk@enexis.nl

Rik FONTEIJN
TU/Eindhoven – The Netherlands
r.fonteijn@tue.nl

ABSTRACT

Enexis is a distribution system operator (DSO) in the Netherlands and one of the front runners for facilitating the energy transition in the Dutch electricity grids. The Interflex project is initiated in 2017 under the Horizon 2020 research and innovation programme of the European Union. The Dutch demonstration project is conducted in the city of Eindhoven, where a mixed urban neighbourhood is chosen for integrating local battery storage in the low voltage (LV) electricity network along with several public charging facilities for electric vehicles (EVs) and local electricity production from photovoltaic (PV) panels. In this project, Enexis aims to solve congestion problems in the network efficiently while maintaining the voltage quality within the Dutch standard boundary limits. To attain this goal, Enexis may purchase the required flexibility from the local flexibility market based on the price of flexibility. In addition to that, the variable connection capacity mechanism is also introduced that allows the DSO to manage the network's congestion efficiently. In this paper, the importance of smart battery storage for testing the proposed concepts is discussed. Furthermore, a short description is given about the current status of the project.

INTRODUCTION

To make the energy transition smoother and faster in Europe, the Horizon 2020 Interflex project is initiated by the European Union. It consists of six demonstration projects in five different European countries (e.g. France, Czech Republic, The Netherlands, Germany, and Sweden). The Dutch pilot is conducted in the city of Eindhoven where a mixed urban neighbourhood with households and business customers is chosen. Several public charging points for electric vehicles (EVs) are installed in the low voltage (LV) electricity network of this neighbourhood. Also, a local smart storage unit (SSU) and some roof-top photovoltaic (PV) panels are connected to this LV network. The PV panels supply excess electricity back to the grid when the local energy demand is low. It is anticipated that the simultaneous charging of EVs or the peak generation from PV panels can cause overloading of the connected cables and the feeding transformer. It can also lead to voltage distortions and increased energy losses in the network. To avoid these problems, Enexis as a distribution system operator (DSO) would typically reinforce the network capacity to accommodate the new load situations. In this pilot, Enexis obtains flexibility from a flexibility market to prevent network's overloading and voltage distortions. Enexis works together with some market parties, who serve the roles of aggregators. These parties control various flexible energy resources and can offer flexibility to the DSO in a flexibility market. In this pilot project, some of the main challenges for Enexis are: 1) to provide smart charging facilities for EVs within the existing network infrastructure, 2) exploring a flexibility market mechanism that might help in preventing and postponing the network reinforcement needs, and 3) introducing SSU at a neighbourhood level for using it as ancillary service.

In this paper, a short description is given about the Dutch pilot & the aggregators. Next, the configuration of test network and various test scenarios of this pilot project are described. After that, a summary is given about the implementation status of various network components. The technical features of the SSU are briefly described. Finally, the importance of SSU in this pilot for testing the flexibility market and variable capacity mechanisms and solving congestion and voltage quality problems are discussed.

PROJECT DESCRIPTION

Enexis, as a DSO, is responsible for the operation, maintenance, and development of the distribution network in its service area. This includes enabling the availability of adequate network capacity and ensuring the voltage quality criteria at different points in the network. As part of the Dutch demonstration of Interflex project, Enexis has developed a grid management system (GMS) to operate and maintain the network efficiently. This GMS stores real-time energy data from the measurement devices and forecasts the expected load demand for the next hours with the help of an in-built simulation tool. It enables Enexis to decide on purchasing flexibility from the flexibility market to avoid congestion and voltage problems in the network. In this pilot, several market parties are involved such as commercial and local aggregators, as described in Figure 1. A commercial aggregator (CA) is defined as a demand service provider who combines multiple short-duration flexibility sources for sale/ auction in an organized energy market. A local aggregator (LA), in contrary, has the responsibility to collect and bundle local flexibility into a bigger aggregated flexibility offering.

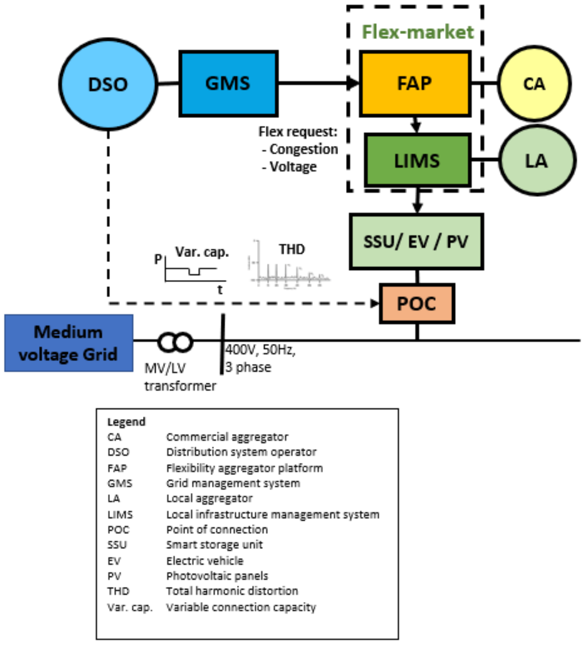

Figure 1: Flexibility market and variable capacity mechanisms

The LA can also provide this flexibility to a CA by contracting flexible energy sources. Enexis may request the aggregators in the flexibility market to offer the required flexibility. However, it is not guaranteed that all required flexibility is available on the market. Parallel to the flexibility market, Enexis therefore obtains flexibility through a 'Variable Capacity Connection' [1]. A Variable Capacity Connection is a contract between a DSO and the owner of a connection on the grid (in this case it's about the SSU connection). The capacity stated in this contract is not a fixed number but is variable over time, as described in Figure 2.

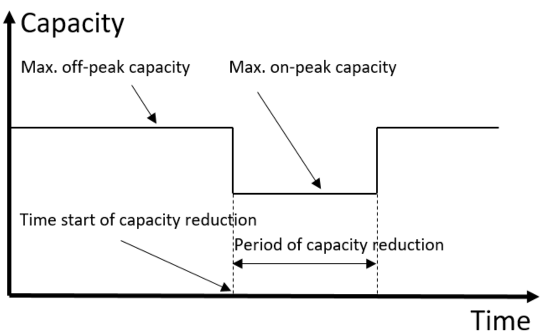

Figure 2: Variable capacity concept

The GMS makes a decision where and when to obtain flexibility based on a load forecast. First, it obtains the contractual flexibility from the variable connection capacity by providing a signal to the LA (who controls the specific customer's connection point that has a variable capacity contract) before requesting the market. This mechanism utilizes the potential of the SSU effectively depending on the network's loading situation. It also ensures more certainty to both DSO and the local aggregators. Under this Dutch pilot project, this concept will also be tested in combination with the flexibility market.

TEST NETWORK CONFIGURATION

As mentioned before, this pilot is conducted for a Dutch neighbourhood (called 'Strijp-S') located in the city of Eindhoven. A typical medium voltage (MV) distribution network in the Netherlands is designed as 'ring shaped', connecting various MV/LV transformer stations. Each MV ring has an open point in its configuration that allows the MV grid to operate radially. In the Strijp-S network, two successive MV/LV transformers from a same MV ring are chosen for this pilot. Each transformer has a capacity of 630 kVA and has eight outgoing LV feeders. Four of the LV feeders of transformer-1 supply electricity to 198 apartment houses, while four feeders of transformer-2 supply 146 apartment houses. The EV charging stations are supplied by one feeder of both transformers. Figure 3 shows detail electrical configurations of the two transformers along with the LV feeders that are monitored continuously in this project.

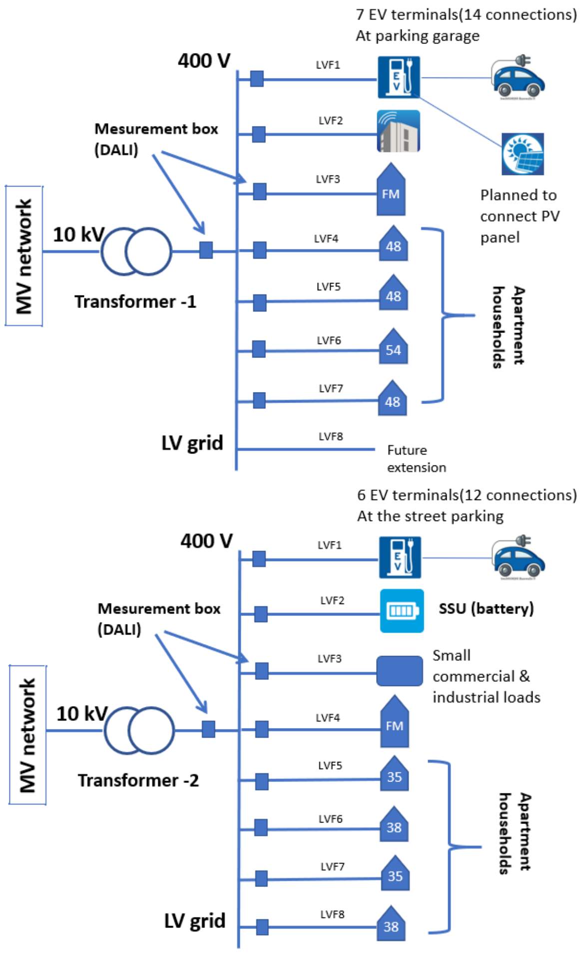

Figure 3: Schematics of LV network used for this pilot

From Figure 3, it can be seen that one LV feeder of transformer-1 supplies to 7 charging stations with total 14 sockets at parking garage; while 6 charging stations with 12 sockets at nearby streets are fed by transformer-2. Besides that, some LV feeders supply to small business loads and other facility management (FM) services of the apartment buildings such as lifts, common lighting etc. One LV feeder of transformer-2 is connected to the SSU which is dedicated for this pilot. The transformer's secondary (LV) side and each LV feeder are connected to measuring box, called "DALI" (distribution automation light). These boxes record every 15 minutes various electrical data such as voltage, current, active & reactive power, total harmonic current distortion (THDI), etc.

TEST SCENARIOS

In this pilot, three use cases are tested. In this paper, the focus is on the use case related to the integrated flexibility market. The purpose of this use case is to validate technically, economically and contractually the usability of an integrated flexibility market based on a combination of static battery storage/ SSU and EV chargers. Also, the concept of the variable connection capacity mechanism will be tested under this use case. Therefore, the following four scenarios are developed to test the effectiveness of the connected SSU in supporting the chosen LV network loads during peak load periods, as first introduced in [1].

Scenario 1: Day-ahead market

All the flex handlings in the local flexibility market will take place by using a day-ahead market. Based on the day-ahead forecast, the flexibility will be requested and offered to the market and eventually be realized as far as possible. The involved parties will follow the proposed fixed scheme for the specific period as agreed mutually.

Scenario 2: Day-ahead market + static variable capacity

In this scenario, one additional feature is added to the scenario 1. During the mutually agreed test period, some fixed amount of capacity of the SSU connection to the grid will be reduced daily at a pre-specified period of the day, as shown in Figure 2.

Scenario 3: Day-ahead market + dynamic variable capacity

In this scenario, one additional feature is added to the scenario 2. The fixed amount of capacity reduction of the SSU connection to the grid can be varied on daily basis at a pre-specified duration per day during the mutually agreed test period.

Scenario 4: Intraday market

This scenario adds an additional feature to the scenario 1. In the scenario 4, the amount of capacity reduction of the flex bidders is fixed, but the specified period may vary on daily basis. The parties can request or offer the pre-agreed amount of energy within a day, independent of the original agreed period made at the day-ahead market. This scenario generally responds to the market at a faster pace.

IMPLEMENTATION AT SITE

The procurement, development and implementation of various needed network components and software tools have started from the middle of 2017. The field testing of software, testing of network components (e.g. SSU) at manufacture's sites and implementation at the site have been successfully completed. The components that have been implemented till now are described here.

Grid management system (GMS)

The GMS system is designed for a day-ahead and intra-day market and can iteratively be executed multiple times within a day. Reference [2] gives more information about the GMS architecture and its functionality. The GMS gives necessary insight into the local distribution network to solve congestion by using the flexibility market and variable connection capacity. It uses smart algorithms to decide where and when flexibility is needed. It consists of several modules as mentioned below:

External input: Load forecast is based on actual field measurement from DALI boxes, daily prognoses of the aggregators, market-energy prices and weather forecasts.

Load Forecasting: The historical measurements are used to predict day-ahead energy demand and consumption of the customers, and the power flows of the networks.

Flex Decision: The main engine of GMS is the flex decision module. It consists of several self-learning algorithms. If congestion is predicted the module defines a price that the DSO is willing to pay for solving congestion.

Messaging: If flex is needed, a flex request is sent to the aggregators connected to the congestion point based on the USEF (Universal smart energy framework).

Portal: The portal is the graphical interface. It gives administrators the overview of messaging and/or system errors. This portal allows to view local load balancing which is controlled by a load manager.

EV charging stations

Figure 4 shows a typical EV charging station that has been installed at the site. It works on three-phase electric power and features EV communication technology. Each station consists of two sockets, each with a maximum capacity of 3x63 A. The charging capacity is always optimally divided among the sockets in use. The connected LV cable to the charging station has a maximum capacity of 173 kVA. So, if all charging stations are occupied, the cable might be overloaded. Therefore, a smart charging logic has been developed to prevent load congestion situation.

Figure 4: EV charging at a parking garage site

Measuring boxes for LV network

In this pilot, all outgoing LV feeders and the MV/LV transformer's secondary sides are equipped with distribution automation light (DALI) boxes. These boxes measure various electrical parameters (e.g. active & reactive power flow, current, voltage, and THDI) of that connection point. Every 15 minutes measurement data is recorded and stored in a big database which can be retrieved any time using the web-based network tool. The DALI system consists of voltage and current sensors and sends the recorded information by using wireless communication. Figure 5 shows a typical DALI system that is connected to the outgoing feeders of a LV cabinet.

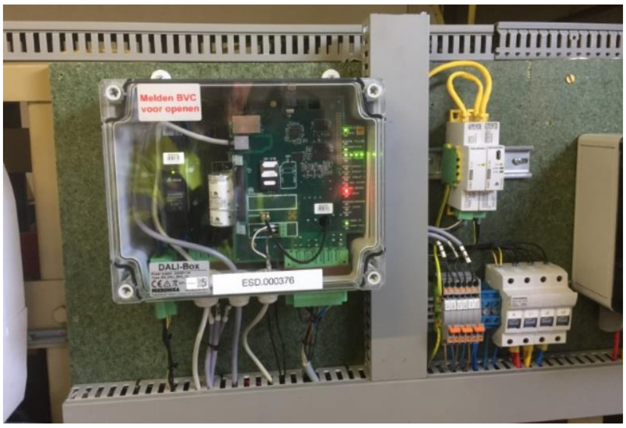

Figure 5: Measuring box (DALI) arrangement

Smart Storage Unit (SSU)

The battery storage system, or smart storage unit (SSU) has been installed at the site, as shown in Figure 6a & 6b. It is a movable 20 feet reefer container with sound suppression. The container is fully insulated and is provided with temperature and humidity control. The SSU consists of several units together such as battery cell storage racks, battery management system (BMS), two bi-directional inverters with LCL filters, energy management system (EMS), data acquisition system (DAS) and climate control equipment. The battery storage uses Li-NMC (Lithium nickel manganese cobalt oxide) technology and has 126 modules. Each module is of 2,5 kW, 48 V. All the modules are arranged in 9 racks. Every rack consists of 14 battery modules and its own battery management system.

Figure 6a: SSU at project site (outside battery cabinet)

Figure 6b: SSU at project site (inside the battery cabinet)

The installed capacity of SSU at Strijp-S site is 315 kWh, with converters capacity of 255 kW (bi-directional). The converter system consists of two separate inverters: one with a maximum power of 225 kW and the other one with 30 kW. This configuration allows to reduce the total system losses. Their working order is controlled by the EMS so that during periods of low demand only the small converter is used while the larger one is only used when more than 30 kW is needed. The SSU is being utilized mainly for demand side congestion management and some amount of voltage support purposes. The LCL filters present along with the inverters in the SSU are designed to provide certain amount of grid voltage support, including short-term power quality problems such as voltage dip, flicker suppression, and reactive power support.

For a battery, the charging and discharge currents are very parameters as they determine the ageing rate and life expectancy of the battery system. The SSU of this pilot has a continuous discharge current of 75 A, while the charging current is 25 A. The state of charge (SoC) during storage and the temperature also affect the ageing rate of the battery. The ageing rate of a such type of Li-ion battery is around 0.5% after the first year and increases gradually to 0.85% in the 10^{th} year. The SSU has a life expectancy of 10 years and overall system efficiency of 93%.

PERFORMANCE OF SSU AT SITE

The SSU at the site has started to operate already since November 2018. It is supposed to have 200 – 250 cycles per year when the depth of discharge is restricted to 80%. In this pilot, the SSU is controlled & regulated by the LA to manage the demand side load in the network. The master controller of the SSU collects all data and communicates to the LA. Therefore, the LA can optimize the charging & discharging of the SSU depending on the network's real-time loading situation. The battery loading information can be obtained from the LA. The SSU's real time loading information can also be accessed by using DALI box. In this pilot, the variable connection capacity mechanism is introduced. By this approach, DSO provides a signal to the LA to limit the connection capacity of the SSU for a certain period in an obligatory manner. Hence, the load congestion level of the network can be regulated as per requirement.
When the network experiences congestion, it may happen that the network voltage level also drops below the standard stipulated boundary limits, as shown in Table 1.

Table 1: Voltage variation limits as per the Dutch & European standards

	Undervoltage limits (in reference to the nominal voltage)	Overvoltage limits (in reference to the nominal voltage)
95% of the weekly measured data (each 10 minutes value)	-10%	+10%
100% of the weekly measured data (each 10 minutes value)	-15%	+10%

As a DSO, Enexis is obliged to provide a good quality voltage to its customers that should meet the boundary limits of the European standard EN50160 [3] & the Dutch standard "GridCode" [4]. During the high congestion periods, generally the voltages at various node points of a network can drop significantly. In extreme situations, it may violate the standard limit values. However, not all level of congestions would lead to voltage violation conditions. It might also be possible that the voltage quality gets affected locally for a specific power quality problem (such as harmonics) in the network, while there is no such load congestion in the grid. One of the targets of Enexis in this pilot is to utilize the SSU as an ancillary service by optimizing its capacity utilization to solve congestion problem and to support voltage quality of the grid locally.
Since November 2018, the charging of EVs at the project site is increasing gradually. It is observed that the SSU is responding (discharging) to the peak load situations, and the charging of SSU is occurring only at the lean load periods. However, it is yet to reach the high peak load congestion situation when the SSU support will be highly needed.
In the first quarter of 2019, more field experiments are scheduled. It is expected that the SSU performance can be observed and understood more from those scheduled field tests. Based on the observational experiences, it will be possible to develop knowledge on the applicability and future scalability of the introduced concepts.

SUMMARY & FURTHER WORK

The Interflex pilot of Eindhoven is intended to test the load congestion situation when a number of EV charging takes place simultaneously. The flexibility market and variable connection capacity mechanisms are currently under field test, which give the possibility for Enexis to understand these concepts by using it in a real network situation. The test scenarios developed under this project will be validated with respect to the market prices. Presently, the SSU installed at the neighbourhood site is operating and supporting the network perfectly, whenever is required. However, it is yet to face a real load congestion situation when its support is genuinely needed. In the near future when an increasing number of EV charging will occur at a time, the actual performance and the effectiveness of the SSU can be observed. Moreover, the importance of SSU for short-term voltage support at a local level will also be tested under this pilot. At present, the DALI boxes are collecting real time load data. This gives information of the actual loading situation of the network. By using the GMS model, a congestion situation will be simulated in the network and the effectiveness of the SSU can be tested. Based on the experiences gained from this pilot, it is expected that the developed knowledge can be used for other networks too on a broader scale.

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n°731289.

REFERENCES

[1] R. Fonteijn, T. van Cuijk, P.H. Nguyen, J. Morren, J.G. Slootweg, 2018, "Flexibility for congestion management: A demonstration of a multi-mechanism approach", *2018 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe)*

[2] R. Steegh, T. van Cuijk, D. P. Khomami, 2018, "Grid management system to solve local congestion", *Will be presented in CIRED conference 2019*, Paper # 576, Madrid, June 2019

[3] European Standard EN50160, 2010, "Voltage characteristics of electricity supplied by public electricity networks", *CENELEC, Brussels*, Belgium, July, 2010

[4] Dutch Grid Code Legislation: "Netcode Elektriciteit per 18 december 2015", *ACM (Autoriteit Consument & Markt)*, 2015, (available in Dutch language only).