Designing and valuing local storage units for T&D deferral using local load data

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0. Abstract

Existing transformers in substations in the low-voltage distribution network will require replacement in the near future as electricity demand will grow. An alternative could be the installation of local storage facilities to cope with peak demand. However, the benefits and costs of these storage facilities are unclear. This research uses unique local demand load data to design local storage units and calculate the value of these storage units. Investment in transformers could then be deferred by 2 to 6 years, representing a value of €24.000 to €37.000. This does not generate a positive business case at this moment, but as battery prices are expected to go down considerably and additional values can be created by e.g. using storage facilities for trading, it is expected that a breakeven could be obtained for the most favourable neighbourhoods by 2025.

Keywords: Distributed Energy Resources, Storage, T&D deferral, DSO

1. Introduction

In recent reports, Dutch network operators have indicated a growth in electricity demand due to increased use for heating and mobility. Next to the increase in demand, local production (mainly solar panels) is already taking off and will grow to substantial levels in the near future. These developments will have implications for the operations of distribution system operators (DSO), as they have to cope with these local developments.

One of the first elements of the distribution assets expected to have insufficient capacity are the substations that transform medium voltage to low voltage. Looking at the present situation at Stedin (Dutch DSO), most substations have a peak load of 50% to 75% of their capacity. Based on Stedin's growth scenarios, maximum usage of nearly half (45%) of the 9000 substations is expected around 2025, when replacement of transformers is needed. Installing storage units (batteries) could help to postpone investments in new transformers, generating financial benefits for the DSO.

The traditional approach of DSOs is to linearly increase their network capacity with the increase in demand. For substations, this would be to replace the transformer with a new transformer with more capacity. Currently, alternatives for this approach are being explored, as DSOs want to and are stimulated to be economically efficient. Distributed or local storage is one of these alternatives. Distributed or local storage units have a large variety of potential benefits (Eurelectric, 2012), among which the deferral of investments in T&D assets (Transmission & Distribution assets). Jim Eyer (2009) states that "*In simplest terms, the T&D deferral benefit is the avoided cost — the cost not incurred by utility ratepayers if the T&D upgrade is not made.*".

Local or distributed storage is a form of Distributed Energy Resources (DER). Although there has been research towards other forms of DERs, the benefits and costs of distributed storage units, when used for deferring investments in distribution assets, are unclear. These values are necessary for a DSO to make a substantiated decision in this respect.

This research gives an overview of previous research towards the value of T&D deferral, which is then used to design the storage units specifically for T&D deferral. This research was namely presented with a unique opportunity to analyse local load data, as a number of substations in the Netherlands were equipped with a meter, for which permission of all connected consumers was necessary. In the past, this was difficult, as (Dutch) DSOs are not allowed to store load data.

After the literature review, the analysis is presented of the demand pattern and peak pattern of different neighbourhoods, which is used to adjust the storage units to the needs of that neighbourhood. Related to the neighbourhood-specific design, the deferral time that could be achieved with these storage units is calculated. Furthermore, the value of this deferral time is calculated.

2. Literature review

Research towards the value of distributed energy resources for T&D deferral has been done by various authors. Gil and Joos (2006) were one of the first to quantify the value of network capacity deferral. Their research focussed on distributed generation as means of deferral. Using the net present value calculation method, Gil and Joos came to the conclusion that the benefits of deferral depends on the timing of the planned or scheduled upgrades (Gil and Joos, 2006).

Zhang et al. (2010) used the same method to evaluate the investment deferral caused by microgeneration for extra high voltage distribution networks. Although the application differs, the applied method for calculating the benefits is the same - which is net present value. Zhang et al. also come to the conclusion that the location of micro-generation is of significant importance to the benefits of that microgeneration (Zhang et al., 2010).

In 2016, Farah Abi Morshed in her thesis also uses net present value calculations to determine the value of deferral of grid reinforcement by using demand-side flexibility (Morshed, 2016). She concludes that flexibility steering can on average postpone grid investment by 2 years. She does state that if grid investment postponement is feasible from a technical perspective, it does not necessarily mean that it is advisable from a financial perspective. Based on the outcomes of her analyses, she made the following conclusions (Morshed, 2016):

"*The financial savings of grid investment postponement by means of demand-side flexibility is highly sensitive to the grid investment cost per kVA per household. Thus, savings from grid investments might be more significant in rural areas in comparison to urban areas.*
The financial savings of grid investment postponement for the DSO are more significant in large districts in comparison to small streets because in the former, more investments are needed to upgrade the city grid and its components.

Financial savings are more significant in areas where congestion is occasional and temporary, in comparison to areas where congestion is persistent and severe, because in the latter high flexibility ordering leads to high cost incurred that will probably outweigh savings gained from grid investment postponement." (Morshed, 2016).

In summary of the above-mentioned research projects, two aspects become clear:

1) Different locations of distributed energy resources in the grid can have significantly different benefits
2) The net present value method seems to be the most accepted method for calculating the value of deferral of T&D investments.

As said, this research was presented with a unique opportunity to analyse local demand characteristics, which is used to adjust the design of the storage units to these characteristics.

3. Analysis load characteristics and designing storage units

The analysis on demand patterns is carried out on five types of neighbourhoods, varying from 100% residential consumers to nearly 100% non-residential consumers (see table 1 for percentages). The load is measured every five minutes over a period of 9 months (01-01-2016 till 01-10-2016). The results of this analysis include load patterns per 24 hours for all days of the week, only weekdays, and only weekend days. Furthermore, the seasonal pattern is analysed by plotting the maximum load per day. These characteristics are later used to design the storage units. These characteristics are visualised for the first neighbourhood (100% residential connections) and can be found in figure 1. The load characteristics and storage designs for the other four neighbourhoods can be found in the appendices.

From these graphs, a number of characteristics become clear. Typically, as the percentage of residential consumers in a neighbourhood decreases, the peak height also decreases, but the peak duration increases. This is visible in the graphs in the appendices, especially for neighbourhoods 4 and 5, which have respectively 26% and 6% residential consumers. The peak duration in these neighbourhoods increase to more than eight hours. The peak also shifts from late afternoon (neighbourhood 1) to business hours (neighbourhood 4&5).

The storage units need to be designed in terms of power and capacity. The power should be sufficient to cover peak demand. Peak demand is defined as demand above the 75%-quantile. This is indicated in figure 2 by the "peak height". The "peak duration" indicates the number of hours per day for which a peak demand can be expected. In this case, the peak demand lasts from approximately 17:00 to 21:45. The peak height multiplied by the peak duration forms the capacity of the storage unit.

This design process is executed for all neighbourhoods and can be found in the appendices.

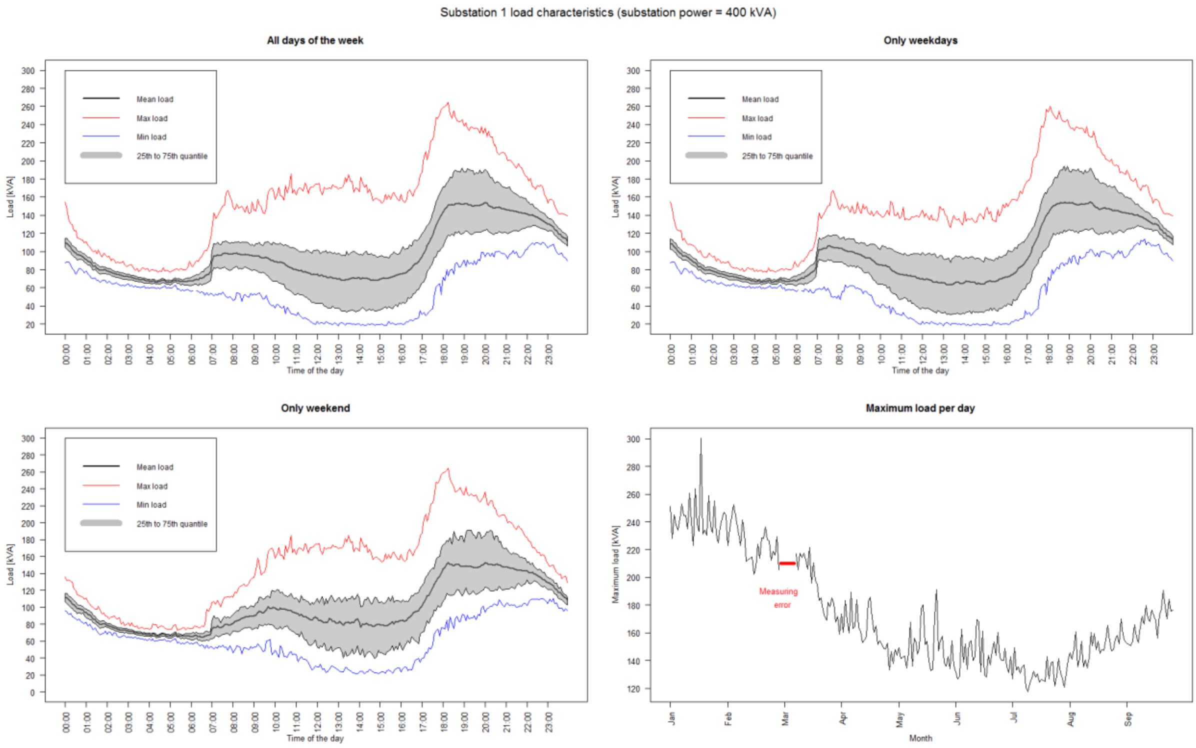

Figure 1: Load characteristics for neighbourhood 1 (100% residential connections)

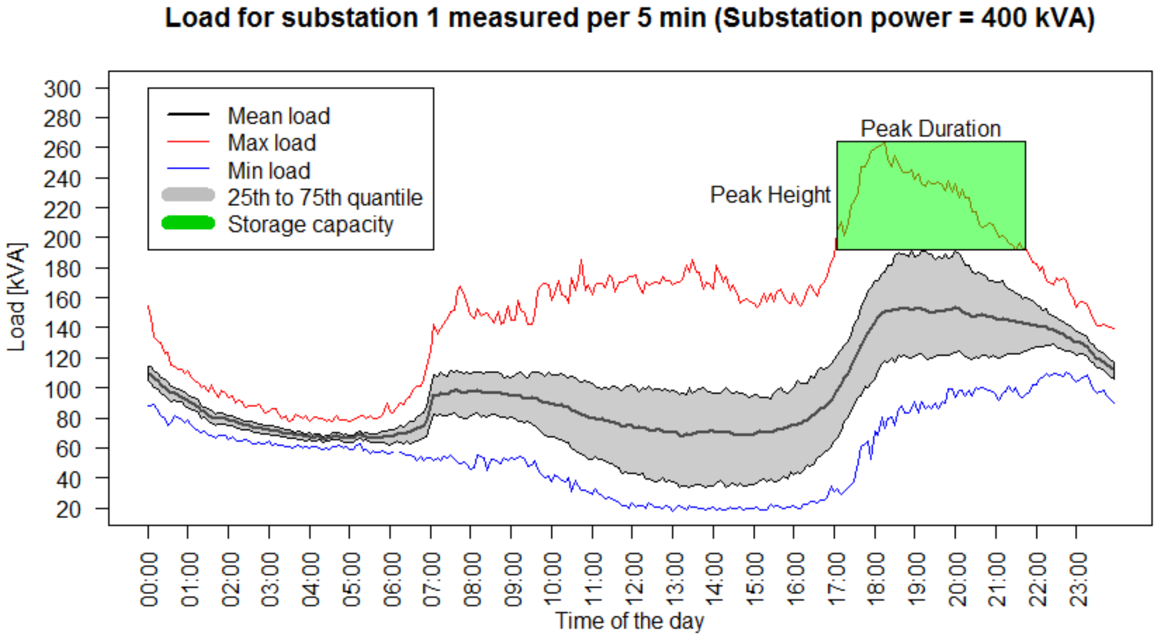

Figure 2: Design of storage unit for neighbourhood 1 (100% residential connections)

From figures 1 and 2, it can be concluded that the current peak load is on 50% to 75% of the maximum capacity and hence still has spare capacity for future growth of electricity demand. With the growth scenarios as developed within Stedin, it is expected that the investigated neighbourhoods will reach their maximum capacity between 2022-2032 and transformers need to be replaced. This conclusion not only applies to the neighbourhoods investigated, but to nearly half of the 9000 substations within Stedin's network.

The replacement of transformers can be postponed by installing storage facilities that can handle the peak demand for a certain period of time. This deferral time is calculated, using the current peak characteristics per neighbourhood and various growth scenarios (developed by Stedin). The results are shown in table 1. Table 1 also indicates the share of residential connections in the five neighbourhoods.

Neighbourhood	Percentage residential connections	Current peak load	Year to reach maximum capacity	Deferral time [years]
1	100%	0.75	2022 – 2023	3 – 4
2	99%	0.75	2022 – 2023	4 – 5
3	67%	0.74	2022 – 2023	2 – 3
4	26%	0.57	2026	2 – 5
5	6%	0.41	2029 - 2032	3 – 7

Table 1: Deferral times for the five neighbourhoods

4. Value of deferral

The value of deferring investments in the substation are compared to the costs of the battery needed for this deferral. The cost of the battery differs per neighbourhood, as the power and capacity necessary to cover peak demand also differs per neighbourhood. The price level used in this research dates from 2014, and is set at €280 per kWh (capacity) and €266 per kW (power) (Ippolito et al., 2014). The battery costs per neighbourhood can be found in table 2.

As determined in previous paragraph, installing local storage units can defer the investment in the substation. The deferral time differs per neighbourhood, but typically ranges from 2 to 6 years. The investment that can be postponed is the replacement of the transformer. The investment costs for a new transformer are estimated at € 50.000. No distinction has been made between neighbourhoods nor circumstances regarding these investment costs.

The lifetime of a battery is approximately 10 years, which is in most neighbourhoods twice the maximum time required for postponing the replacement of the transformer. Therefore, in the calculation the initial calculated value is doubled, indicating that the battery can be used twice.

To determine the value of deferring investments a NPV calculation has been carried out, using discount rates from 5% to 10%. This discount rate represents the average costs of capital for the DSO and indicates how much value an investment or project adds. The results of these calculations are shown in table 2 underneath. The range for savings occurs because of the range in discount range, but also due to the range for deferral time.

From this table, it can be concluded that the maximum "savings" that can be obtained are between €24.000 and €37.000 for the different neighbourhoods. This is still well below the investments costs of batteries, that are in the order of magnitude of €100.000. Various parameters in the calculations carried out can be further elaborated upon to get to a more accurate picture. The most important one, with the biggest impact, is the development of prices of batteries. It is envisaged by the industry as well as science, that price will decrease by nearly 50% in 2025 compared to 2014. This would bring a breakeven point nearby.

Neighbourhood	Savings	Battery costs
1	€13.616 - €31.698	€121.800
2	€17.730 - €37.907	€107.240
3	€ 9.298 - €24.868	€126.000
4	€ 9.298 - €37.907	€94.360
5	€13.616 - €24.342	€91.560

Table 2: Savings and costs per neighbourhood

5. Conclusions and recommendations

Using low-voltage storage capacity could defer investment in new transformer in substations by 3 to 7 years. The value of this deferral does not outweigh the investment costs in storage capacity at this moment of time. Even in the most favourable neighbourhood the investment costs are still not covered for 50%.

Further reduction of battery costs is envisaged and is expected to be in the order of magnitude of 50% by 2025. This time horizon coincides with the period of replacement of nearly half of the substations at Stedin. Such a price reduction would bring a positive business case nearby for the most favourite neighbourhoods.

In order to arrive at a breakeven business case additional values are required. These could be found in using the storage facilities for trading purposes or for locally balancing electricity production and demand, that will become more urgent as local electricity production (mainly by solar panels) will increase in the near future.

As a positive business case could become realistic by 2025 for the most favourable neighbourhoods, it is recommended to start further investigations in battery price developments and additional values that could be obtained. Next to that, more specific circumstances in neighbourhoods and substations should be taken into account. If developments are in favour for the business cased described in this article, a pilot could be designed and realised towards 2025 when large number of substations need to be upgraded.

This research used actual neighbourhood load data to design the storage unit for specific neighbourhoods, as previous research indicated that the different locations of DERs in the grid significantly changes the benefits of those DERs. This research also showed that different locations of storage units have significantly different benefits, using the ratio between residential and non-residential connections in a neighbourhood. It can be concluded that the neighbourhoods used in this research differ in terms of peak height, peak duration, and seasonal influence. The conclusions made regarding these load characteristics of these neighbourhoods can also be used for the determination of other benefits of local storage units, which can be found in the research by Eurelectric (2012).

6. Acknowledgements

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7. Appendices & references

Eurelectric (2012) *Decentralised storage: impact on future distribution grids, Task force smart grids, flexible loads and storage*, Union of the Electricity Industry, Brussels, Belgium

Eyer, J. (2009) *Electric utility transmission and distribution upgrade deferral benefits from modular electricity storage*, Sandia report, June 2009

Gil, H.A. and Joos, G. (2006) *On the quantification of the network capacity deferral value of distributed generation*, IEEE transcations on power systems, Volume 21, Issue 4, October 2006

Ippolito, M. G., Zizzo, G., Telaretti, E., Rizzo, R., & Graditi, G. (2014). *Technical Economical Evaluations for Distributed Storage Applications: An Italian Case Study for a Medium-Scale Public Facility*.

Klein Entink, M.E. (2017) *Benefits of local electricity storage for a DSO*, Master thesis, Delft University of Technology

Morshed, F.A. (2016) *The prospects of flexibility on congestion mitigation against network reinforcement*, Delft University of Technology, August 2016

Zhang, Y. and et al. (2010) *Evaluation of investment deferral resulting from microgeneration for EHV distribution networks*, IEEE Power and Energy Society General Meeting, September 2010

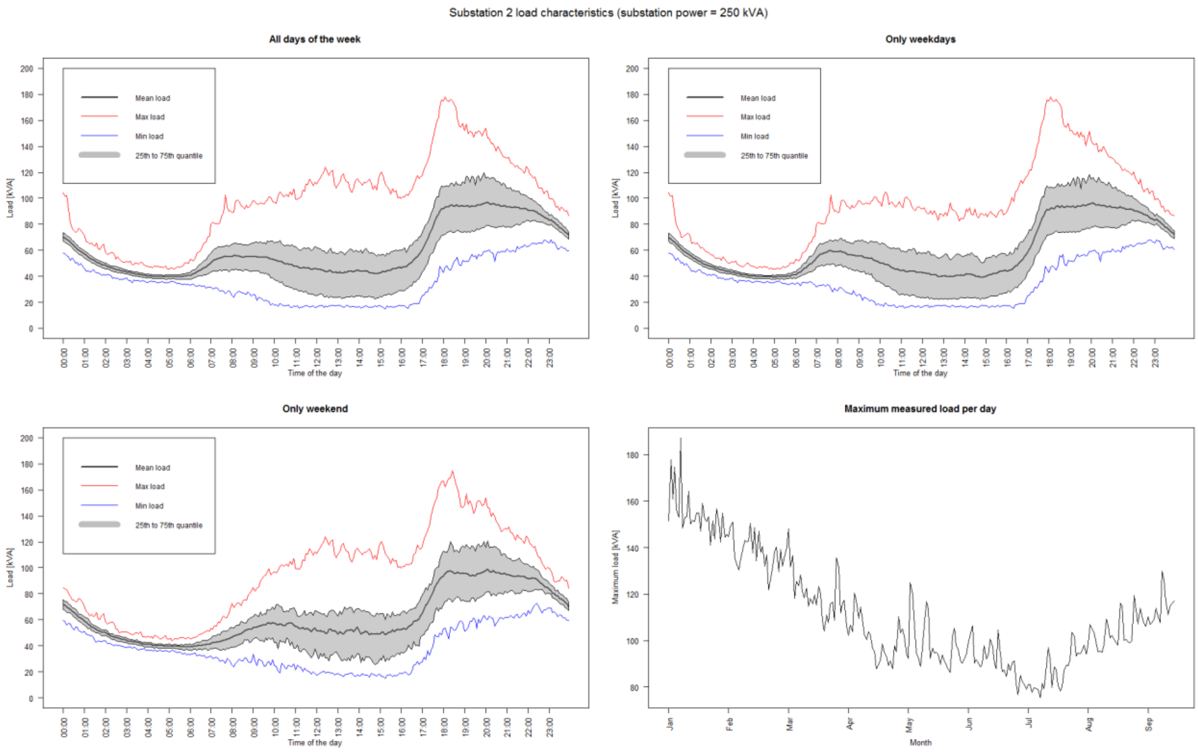

Figure 3: Load characteristics for neighbourhood 2 (99% residential connections)

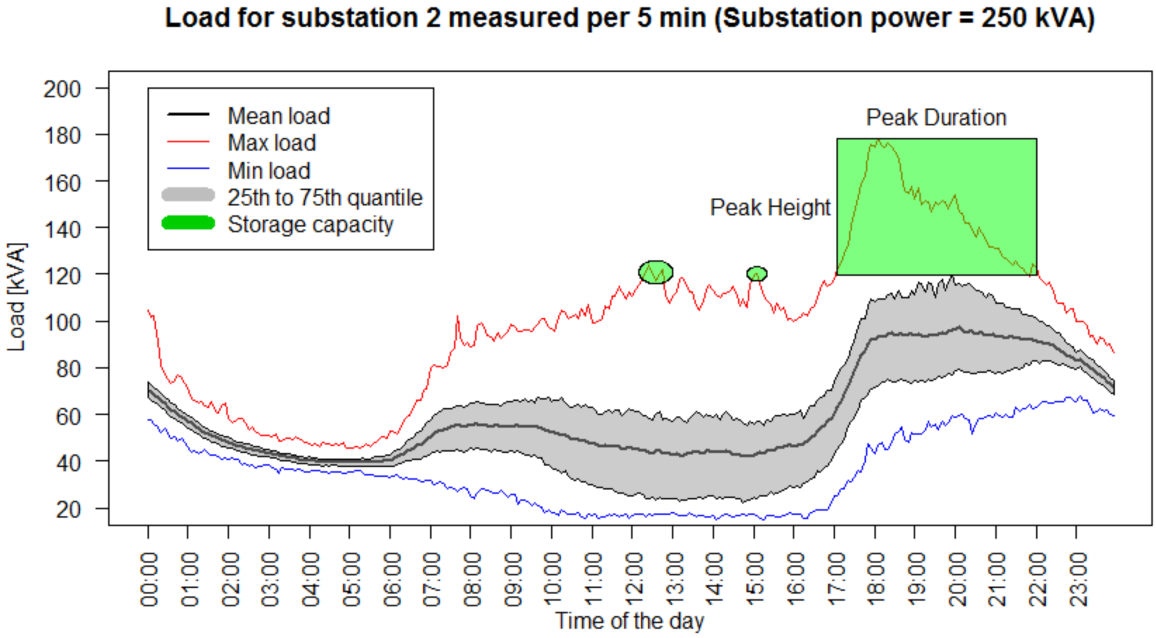

Figure 4: Storage design for neighbourhood 2 (99% residential connections)

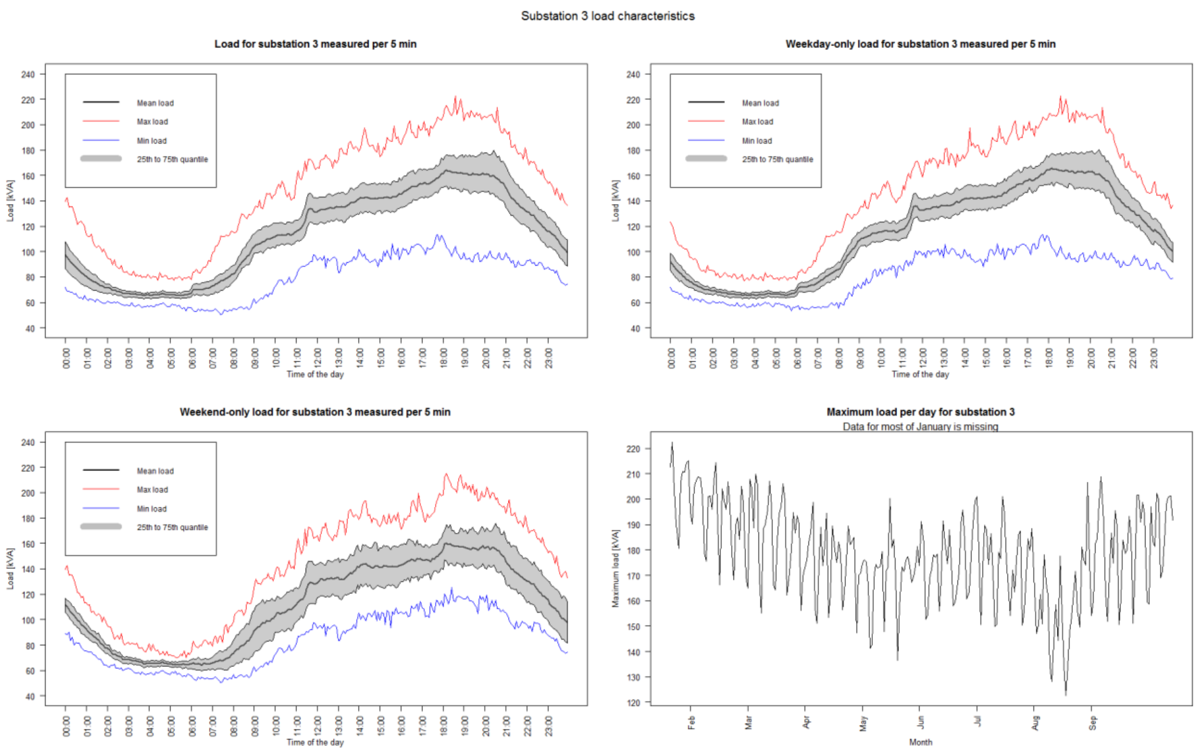

Figure 5: Load characteristics for neighbourhood 3 (67% residential connections)

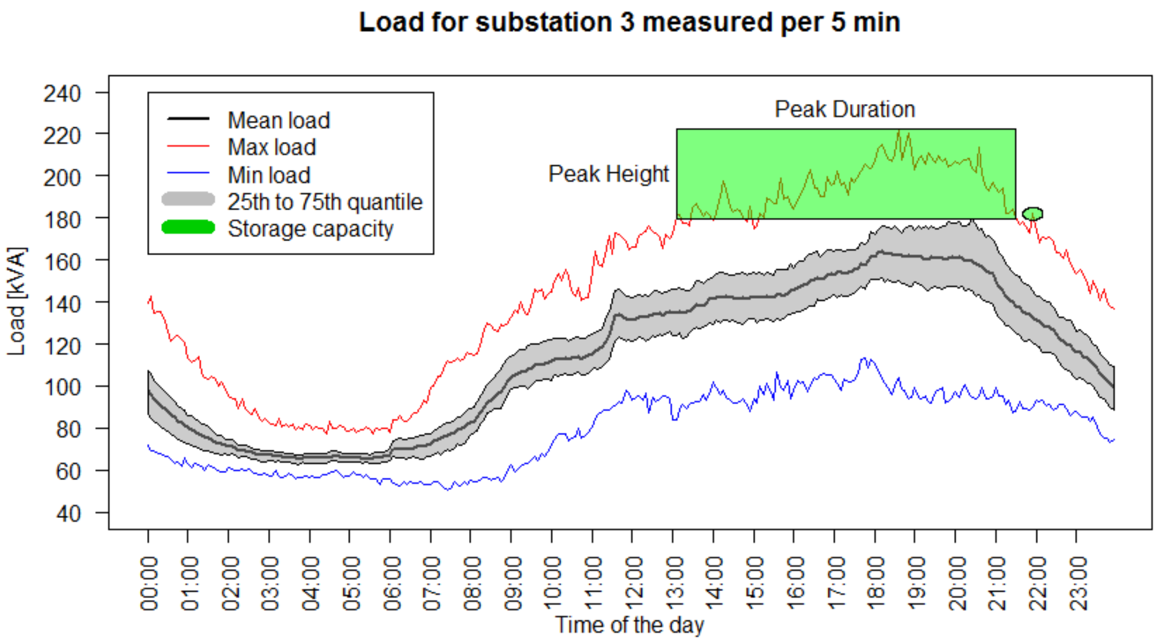

Figure 6: Storage design for neighbourhood 3 (67% residential connections)

Figure 7: Load characteristics for neighbourhood 4 (26% residential connections)

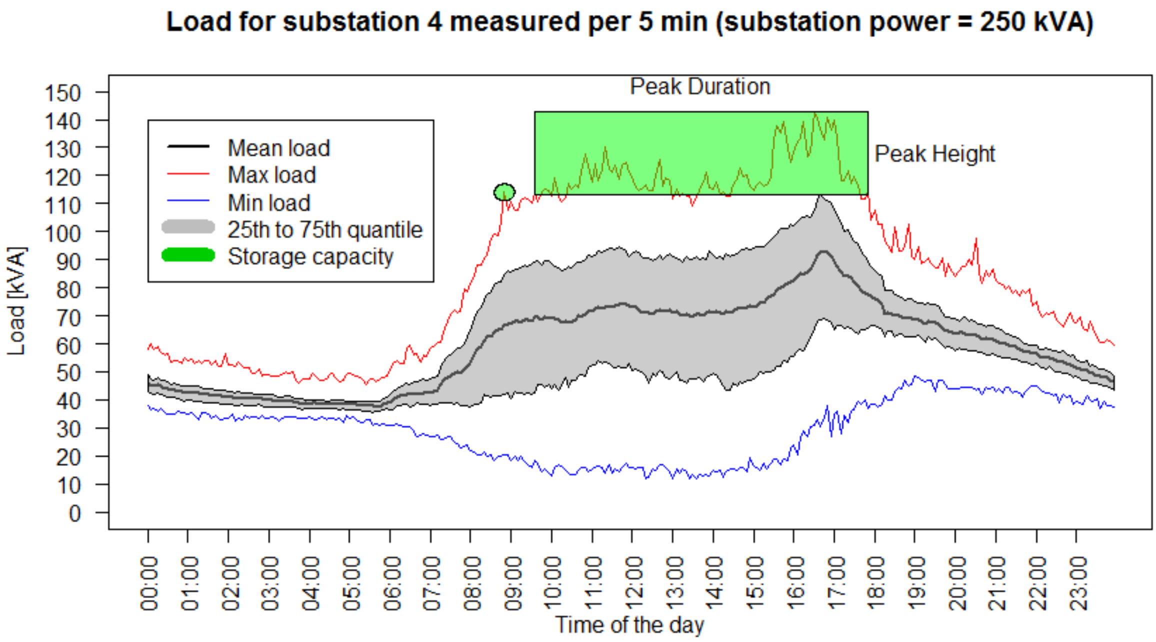

Figure 8: Storage design for neighbourhood 4 (26% residential connections)

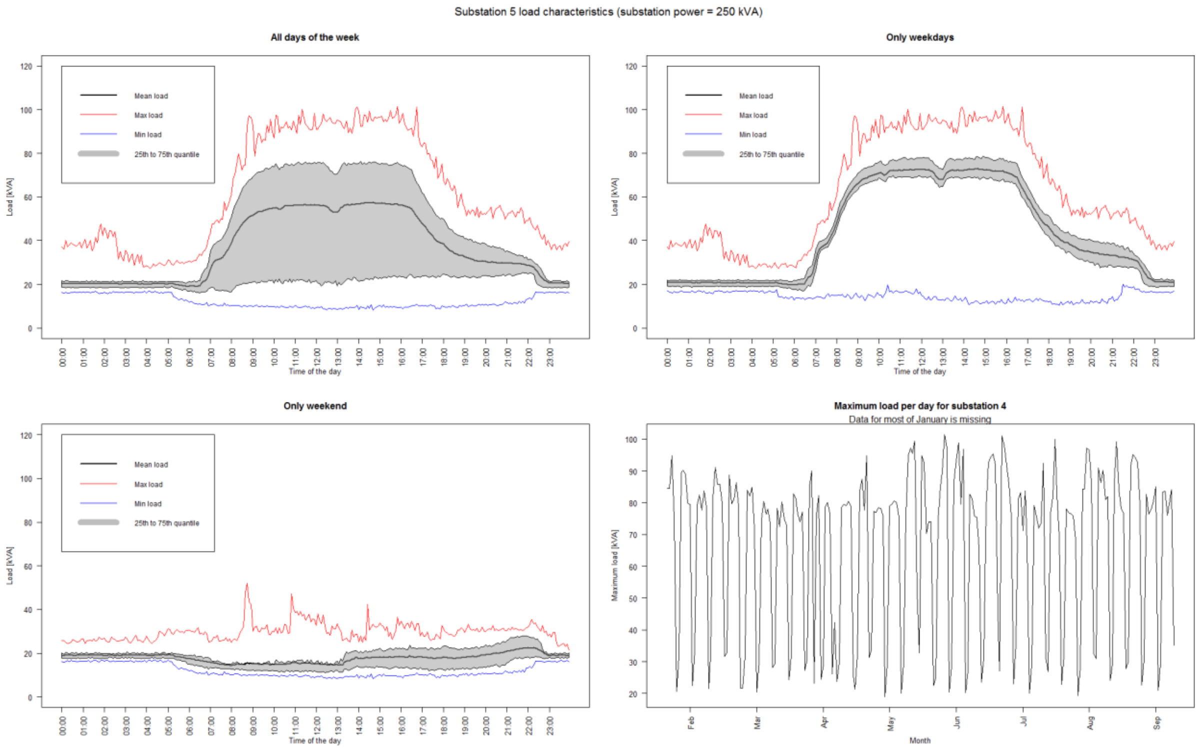

Figure 9: Load characteristics for neighbourhood 5 (6% residential connections)

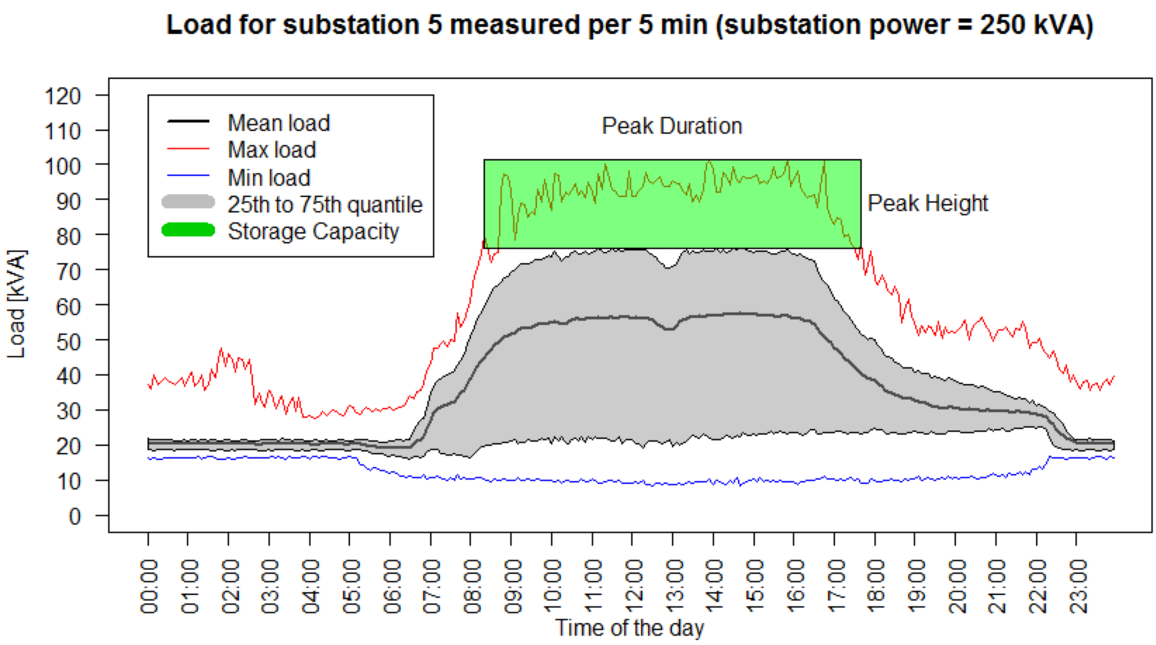

Figure 10: Storage design for neighbourhood 5 (6% residential connections)