TESTING GRID-BASED ELECTRICITY PRICES AND BATTERIES IN A FIELD TEST

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ABSTRACT

Using the flexibility of batteries and households, the overall stress on the network can be reduced, reinforcements to the grid can be postponed or even avoided, and losses can be minimized. However, the current pricing mechanisms do not stimulate to obtain these goals. Within the GridFlex Heeten project, we calculate and send these control signals to 24 household batteries and send incentive signals to households. Determining the control and incentive signals depends on the criteria we take for our optimization. Therefore, the entire network, including geographical layout is modelled and described in a simulation tool called DEMKit.

INTRODUCTION

Historically, all electricity production was centralized in large power stations. Nowadays, there is a shift to renewable energy sources on a local level, giving rise to more uncontrollable and hard to predict production that is also more correlated. Simultaneously, the demand for energy rises due to an increased usage of e.g. electric vehicles and heat pumps. The electricity consumption of these devices is highly synchronized and typically the resulting peaks do not coincide with peak production of renewable energy. As the distribution grid was not designed to handle these extreme peaks in energy, it may be overloaded if we do not use some smart control or offer incentives to shave the peaks [1].

However, the current pricing mechanisms do not give customers incentives to consume electricity at times when it is better for the networks or to spread their consumption over the day. Time-of-Use pricing or peak pricing tends to only shifts peaks and may even increase the simultaneity of loads, e.g. for charging electric vehicles [2].

ABOUT THE PROJECT

The aim of this work is to realize a local energy market to test innovative price mechanisms, in combination with local electricity production and storage. The used incentives have the goal to get a better match of supply and demand. This work is part of the 'GridFlex Heeten' project with a consortium of Enexis B.V.(project manager), Endona U.A., Escozon U.A., Enpuls B.V., Dr Ten B.V., ICT Group N.V. and the University of Twente [3]. As Endona U.A. has obtained an exemption on the Dutch energy law for experimenting with price mechanisms, we can validate these concepts in a field test.

In this project, we collaborate with all 47 households behind a single transformer in a neighbourhood within Heeten, a village in the Netherlands. Some of these houses have PV installations and some of the houses (24) get a 5 kWh sea salt battery, developed by Dr Ten [4]. The distribution of these assets is planned such that some houses have none, some have both and some houses have only a battery or only PV. All households provide us with access to their smart meter data and their PV production, giving us insight into their local energy streams.

GOALS

The goal of the project is to use the flexibility of the batteries and the households to reduce the overall stress on the network thereby postponing or even avoiding reinforcing the grid and reducing the losses in the grid.

Degradation

One of the options to reduce the stress on the network is to focus on minimizing the degradation of the LV-cables and the transformer. To quantify the degradation of these assets under a certain energy consumption profile, several models have been developed [5].

Losses

Another objective of importance is to reduce the losses in the system. Next to their direct costs, losses also cause the assets in the network to heat up, leading to degradation. As losses scale quadratically with the current, minimizing the losses will automatically reduce the peaks in the energy profiles [6].

CO_2 reduction

One of the reasons to switch to renewable sources of electricity is to reduce the negative influence of a high CO_2 output to the environment. Traditionally, the energy is produced at large power plants, often using fossil fuels to generate the electricity, resulting in a large CO_2 output.

Switching to renewable energy sources helps to reduce the output [7].

APPROACH

To reach the goals described above, we use the following approach. A central controller sends signals to the households and the batteries (which are the only smart devices which can be planned). For the households, these signals should contain information based on which they are stimulated to use their flexibility to relieve the stress on the network. We refer to these signals as *incentive signals*. The occupants of the household can decide to act based on the incentive signals, e.g. by starting their washing machine at a later time. Next to that, we also send signals to the 24 placed batteries. These are called *control signals*.

One important research question in the project is: what signals are sent to the households and batteries, and how these signals are calculated? To fulfil the goals, a general requirement is that the setup should be scalable and that the computation times should not get too large.

As our aim is to decrease the network stress, we need a detailed model of the grid, also taking into account the spatial layout of the electricity network. As further input to this model, we get data from 47 houses every minute. In this data, we separately get information of the baseload, the PV generation, and the battery load.

The derived model will be integrated into a simulation tool (DEMKit), together with the measurement data. This allows us to calculate the state of the entire network. Based on this, the control of the available flexibility follows the following three steps [8]:

1) Make a *forecast* of the expected electricity profile of the individual households for the upcoming time periods.
2) *Plan the control signals* for the battery, and *determine incentive signals* for households based on the forecast.
3) *Control devices* to implement the planning based on real-time data.

Determining the control and incentive signals depends on the criteria we take for our optimization. This implies that depending on the chosen criteria we get different signals. Existing starting points for these signals could be the concepts used by e.g. the PowerMatcher, or within profile steering [9,10].

The relevant aspects of this approach are discussed in detail in the remainder of this paper. Please note that as this project is still ongoing work.

MODEL

We model the entire neighbourhood, taking into account the houses, the underground cables, the transformer, and the geographical layout of all of these. This way, we get a realistic representation of the neighbourhood. We can see this representation as a graph, where houses, cable joints, and the transformer are the nodes, and the cables are the edges. This makes it easier to analyse the network. The concrete network of the test area can be found in Figure 1.

As mentioned, the goal is to reduce the overall stress on the network. For this, we do not only look at the maximum occurring peaks, but we also take into account both the losses in cables and transformer, and degradation of the cables and transformer.

The only way we can influence the loads within the network is by sending control signals to the 24 placed batteries, and by sending incentive signals to the households. The occupants of the household can then decide to act based on the incentive signals.

Figure 1: *A map of De Veldegge. The electricity cables are shown in green, the connection cables in blue, the houses in red, and the transformer is in pink*.

CONTROL AND INCENTIVE SIGNALS

As already mentioned, we can only influence the energy consumption patterns of the participants by providing them with certain signals. These signals can be coupled to a pricing scheme or a global optimization approach.

It is obvious that in a (mathematically) optimal solution the overall load would be totally flattened over time for the transformer, the cables as well as the houses. Therefore, our incentives should aim for approaching this global optimum. However, we also want to take into account to which extent people consider a certain incentive scheme as fair [11].

In the following sections, we explain a few of the mechanisms we plan to use and evaluate in this project in more detail.

Degradation

Based on the degradation models in our simulation tool, we can calculate control signals that are sent to the batteries that allow the batteries to adapt their usage such that the degradation is minimized, and incentive signals that are sent to the participants to inform them how to shift their consumption to minimize degradation. One possible way to define these signals is to use a pricing scheme in which the energy price becomes higher if the assets are degrading faster.

Losses

As with minimizing degradation, we can calculate the control and incentive signals using the models in our simulation tool. The control signals allow the batteries to change their behaviour in order to minimize losses. The incentive signals stimulate the households to shift their consumption such that the losses are minimized. This can be realized with a pricing scheme wherein the energy price becomes higher if the losses are higher.

Capacity

Currently, Dutch households simply pay for their annual electricity per kWh, though large consumers also pay a capacity tariff. The advantage of such a capacity tariff is that customers are directly stimulated to keep the peaks in their energy usage to a minimum. A possible disadvantage of capacity tariffs is that they do not take into account the location of possible peaks caused by others in the network.

To address this shortcoming, a capacity tariff could be enforced at the transformer instead of having it at the house. An issue here could be that the peaks at some locations within the low-voltage network may still be relatively high.

Shapley value

The problem with losses and peak loads in the grid is that they depend not on an individual household but on a group of households. Therefore the costs associated with a household should be related to the added cost an individual household adds to the cost of a group. This is precisely what the Shapley value expresses [12]. This value also has some other attractive properties such as efficiency (the total gain is distributed), symmetry (if two individuals add the same to each group, then their Shapley value is the same), linearity (forming coalitions between the individuals does not change the Shapley value) and zero player (an individual that adds nothing, has a Shapley value of zero).

If we see the energy profiles for each household as its contribution, we can use the Shapley value to indicate how much the household has contributed to incurred cost (losses/stress/degradation) of the network. To concretize this, we first have to specify a way to calculate the costs that a group of households generate. For this, we can use different costs functions based on the optimization criteria.

The downside of using this value in combination with cost functions based on losses or degradation is that it is heavily influenced by the location of the customer in the network, which may not be perceived as fair. This is due to the fact that electricity used by households at the end of a cable need to travel a longer distance, therefore incurring more losses. However, this may be overcome by making some additional assumptions on how losses are distributed over households.

CO_2 reduction

To reduce the CO_2-footprint of a neighbourhood, it is commonly best to keep renewable energy produced in the neighbourhood behind the transformer. This does not necessarily coincide with reducing the stress on the network, as batteries are only requested to charge the energy from PV panels which is not consumed directly. This might still leave high peaks in the energy consumption patterns.

DATA FLOW

The flow of data for the considered field test is given in Figure 2. Each of the 47 houses has a smart meter, which is connected to a home energy management system (HEMS). If PV panels and/or a battery are present, the HEMS separately gets the data of these devices. The HEMS sends the data to a cloud service every minute.

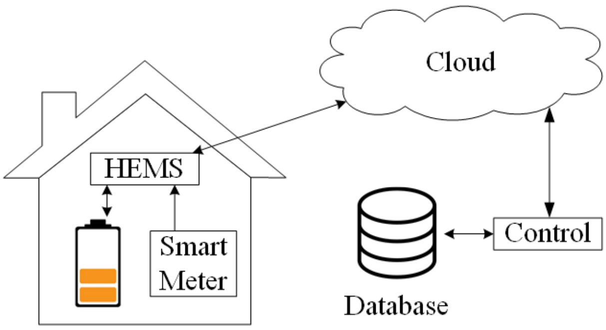

Figure 2: *Dataflow in the field test*.

Households have real-time access to their own data. The control algorithms also receive this data with a minute time resolution and store the data in a database. This database acts as a source of information for our simulation tool and later also for the real-time control signals of the batteries and the real-time incentive signals sent to the households. Concretely, the data is used as an input for calculating specifications or properties of households, but also for making predictions on e.g. the baseload profiles of households or the generation profiles of PV installations. Such data, together with the optimization criteria, form the input for calculating the control and incentive signals. These are then sent back to the batteries and households.

IMPLEMENTATION

The entire network is modelled in a simulation tool called DEMKit [13]. In this simulation tool, models of different assets commonly found in electricity network are implemented and can be used to create a realistic representation. Next to that, several optimization algorithms are available to calculate the control signals and incentive signals with.

DEMKit

The Decentralized Energy Management toolKit, or DEMKit for short, is a smart grid optimization and simulation tool developed at the University of Twente. DEMKit uses the TRIANA concept [14]. The simulation tool follows a cyber-physical systems approach, in which the effects of steering algorithms on assets in the grid can be tested.

Battery model DiBu

To compute a planning for the batteries and predict the behaviour of the batteries as a response to our planning, we use a detailed model for batteries in DEMKit. This DiBu-model (short for Diffused Buffer) accurately predicts the State of Charge of batteries based on the internal battery voltage. The current battery voltage is determined based on its previous voltage by using different update steps, depending on if the battery is (or has been) charging or discharging [4].

SUMMARY AND OUTLOOK

In this work, we presented the GridFlex Heeten project, in which we test the influence of different control or incentive signals within a neighbourhood of 47 houses to relieve the stress on the electricity network. We do this by calculating optimal control signals for batteries, and incentive signals for the households, based on different optimization criteria. Possible criteria for optimization are: minimizing degradation, losses, and CO_2. The electricity network of this neighbourhood is modelled, taking the geographical layout into account. This model is implemented in a simulation tool (DEMKit). The GridFlex Heeten project runs until the end of 2019. At a later stage in the project, possible ways to set up a local energy market are further investigated.

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