Tool for market interaction and service delivery verification

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TABLE OF CONTENTS

1 Introduction

The EcoGrid 2.0 project develops demand-response based services provided by aggregations of residential loads for both the Transmission System Operator (TSO) and Distribution System Operators (DSOs) and tests them on a real market platform with a large number of real consumers. For services traded between Aggregators and the TSO, the project focuses on *Manual Frequency Restoration Reserves*. The services are provided by aggregations of thermostatically controlled loads such as heat pumps and resistive heaters of residential customers. Traditional system services are usually offered by power plants which sell the option to ramp their power generation up or down. Allowing aggregations of distributed residential appliances to provide similar services introduces several challenges.

First, residential units, such as heating units or batteries of electric vehicles, are constrained by the comfort of their owners and therefore are only able to shift power consumption in time. Increasing their power consumption will ultimately require decreasing it later on and vice versa. Even though block bids have been introduced in various markets (e.g. EPEXSPOT), it is not possible to trade such asymmetric bids yet.

Second, large market participants belong to balance responsible parties (BRPs), requiring them to plan their power consumption a day in advance. Each BRP sends schedules to the TSO with their planned power consumption and they are required to stick to these plans. When power plants offer system services, such services can easily be verified since large units must have high quality measurement instruments, allowing for a precise estimation of deviation from the BRP-announced plan. In contrast, residential power consumption is forecasted and the BRP buys the corresponding energy in the markets. These forecasts can be precise because the forecast is made on the aggregate of large pools of consumers. The smaller these pools are, the more difficult it is to make accurate forecasts, increasing the challenge of verification of demand-side services. In EcoGrid 2.0 aggregations of electric heaters and heat pumps are controlled. However, their electric consumption is measured together with the remaining uncontrolled loads of each household through one smart meter. In this setup, flexible residential units are not measured separately from the rest of the households and no accurate forecast can be made on a single household. Hence, it is not clear how to identify when an aggregator has initiated a reduction or an increase of power consumption through a control signal and when the load changed spontaneously.

Finally, the distributed nature of load aggregations makes it more challenging to measure the real total power consumption. Instead of one central power measurement, hundreds, potentially thousands of distributed devices must be measured. The roll out of smart meters might make this possible. The smart meter system to be rolled out in Denmark will initially collect data on a 1 hour time scale but will move to a 15-minute time scale and it is the 15-minute time scale metering interval that is the basis for the EcoGrid 2.0 project. Even with measurements every quarter-hour, transmission of this data to the system operator as well as the other market participants will occur with a much lower frequency and with a relatively long guaranteed delivery time of more than 24 hours. If a future market for system services is to rely on this infrastructure, these constraints must be considered, when designing the market as well as the service verification.

This report addresses these challenges by presenting the concepts for service delivery verification developed in the EcoGrid 2.0 project.

2 Market Design

The EcoGrid 2.0 project investigates how Aggregators of distributed energy resources (DERs) could offer services to the system operators. In particular, EcoGrid 2.0 considers Manual Frequency Restoration Reserve as a service to the TSO.

To allow DER units to participate in the market, the concept of asymmetric blocks has been introduced (N. O'Connell n.d.). For EcoGrid 2.0 a special market setup has been defined in (J. Mehmedalic 2016). The setup proposes a market mechanism based on a rolling horizon method, which minimizes the total reserve acquisition cost of the TSO.

Figure 1 gives a brief overview of the market process.

As part of the market specification, the TSO must identify the needs of the system (*Reserve requirements from TSO*). In parallel, services are defined, which can be traded in a market and guarantee the necessary reserve requirements (*Ancillary service definition*). This includes defining all the control parameters, acceptable delivery ranges and verification metrics. Further, the process of how schedules for residential load aggregations together with deviation tolerances are established must be defined in detail. Service specifications might influence the systems reserve requirements.

During the day of operation, the TSO provides a service request forecast to all market participants (*TSO service request*). The market participants can then bid for up and down regulation services including asymmetric block bids. In the Nordic region, the Manual Regulating Power Market is cleared through the merit-order NOIS list. This clearing method is not applicable to asymmetric block bids, therefore a new optimization algorithm clears the bids from the market participants *(Bidding + clearing + contracting)* on an hourly basis with a 15 minute resolution. Solving this difficult optimization problem in real time could be an issue (N. Vespermann 2017). Bids are entered as deviations from a schedule, defined by the BRPs (each aggregator belongs to a BRP that is used to transfer bids to the market).

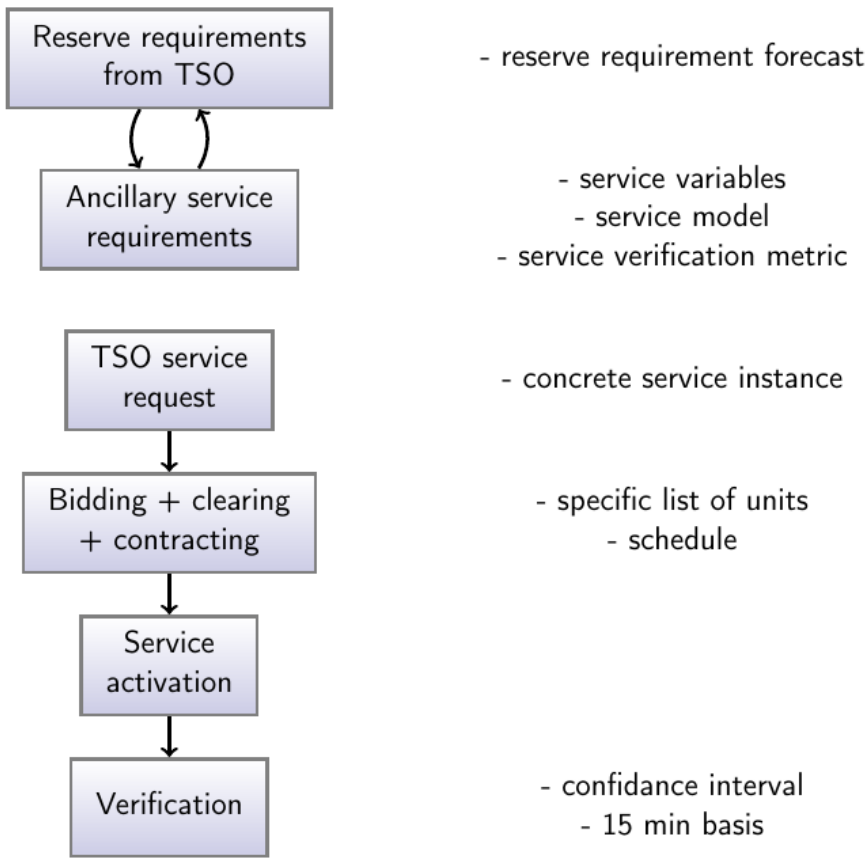

Figure 1: Overview of the market process.

2.1 EcoGrid 2.0 specific design

In the EcoGrid 2.0 project, no BRPs nor TSO are involved. This might introduce some differences between the EcoGrid 2.0 demonstration setup and what will be possible in the real markets. The two main approaches that could be pursued in the real market are based either on schedules or on agreed baselines. The control capabilities of the demonstration make it difficult to track a schedule. Instead of schedules transmitted from the aggregator to the BRP (and then to the TSO), the project will use baselines[1], consisting of load forecasts for aggregations. Verification is carried out by using these forecast values and real measurements, which will be evaluated using 15-minute smart meter data. As no BRPs are participating in the project, aggregators are not held accountable for deviating from their baselines during times when they are not offering system services. In a real setup, they most likely would be held accountable by their BRP, due to the BRP's balance obligations.

[1] The baseline is discussed in detail in section 4 of this deliverable.

3 Service Specifications

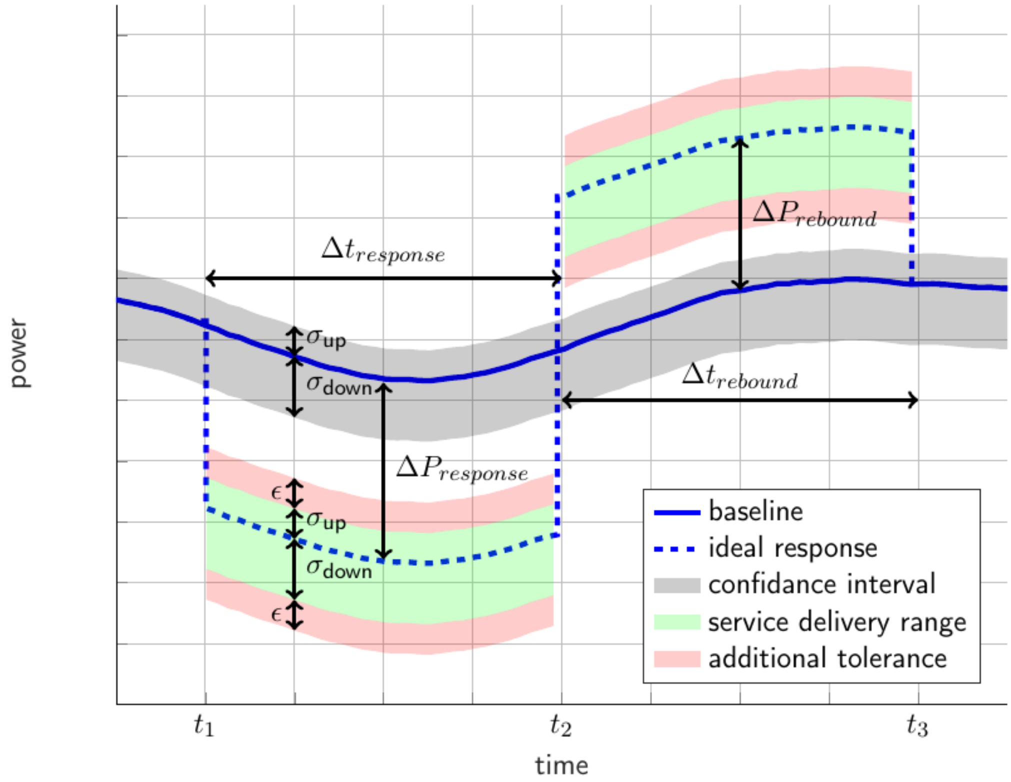

Figure 2: Sketch of a load reduction service with rebound showing confidence interval, acceptable power interval during service delivery and the additional tolerance

Figure 2 shows the sketch of a load reduction service of $\Delta P_{response}$ for a time period equal to $\Delta t_{response}$. After delivery, the aggregator's aggregated load will rebound. During this period, the same logic applies as during service delivery. The Aggregator or its associate BRP has transmitted a schedule to the TSO prior to the bidding process. This schedule is depicted in blue. The aggregator has to stick to this schedule as close as possible. Power consumption in a certain interval is considered acceptable and is not penalized (grey area). Currently this value is defined as 1% for BRPs of generation units. A tolerance for BRPs of residential consumption could define a much larger tolerance in the future. In EcoGrid 2.0 such a schedule is replaced by the baseline and the acceptable range is defined as the confidence interval of this baseline with a width $\sigma_{up} + \sigma_{down}$.

During service delivery, the aggregator is required to reduce the load by $\Delta P_{response}$. It is assumed that the load lies within the grey confidence interval had the service not been activated. The accepted power consumption interval during the service period is defined by the green area, which is the confidence interval of the schedule, shifted by $\Delta P_{response}$. Theoretically, if the

$\Delta P_{response}$ is small and the confidence interval is large, then the service delivery range can overlap with the confidence interval. Such a condition would make verification difficult, if not impossible.

In addition to the acceptable interval, an additional tolerance interval ϵ is defined. In this interval, a linear penalization is introduced, resulting in zero reimbursement for service delivery, if a measurement lays outside of this tolerance range. The same logic applies for the rebound effect.

4 Baseline

Aggregators that offer system services change residential load patterns to stabilize the electricity grid. To evaluate their performance, a model of the load has to be established, which can answer the question, how the load would have behaved, if the aggregator had not controlled and manipulated the consumption. This hypothetical power consumption is called the baseline. In the EcoGrid 2.0 project, this forecast will be used instead of an aggregator schedule for the part of the portfolio that delivers the service if future service specifications will be based on schedules. In a real setup, an aggregator would use a similar tool, to evaluate its own performance and to create schedules for its associated BRP. The BRP is then able to create load and generation schedules for the TSO.

Since residential loads do not plan their power consumption ahead of time and since load patterns are subject to stochastic customer behavior, creating such a model/baseline is challenging.

4.1 Baseline Tool

The baseline tool takes a list of household IDs, a start time, and duration of service delivery as an input. The tool returns a baseline time series for the specified houses. This tool will be used for offline flexibility characterisation as well as for service delivery verification.

To do this, several functions are necessary, which are called from within the baseline tool:

1. A function which downloads and cleans Smart Meter data for the individual houses. Since baselines have to be generated for different aggregations, the individual household profiles have to be stored. Cleaning the data means fixing time issues from the database (summer-winter-time switch), identifying and compensating for missing data points and storing the result.
2. In EcoGrid 2.0, the Smart Meters communicate with a central database every 12 hours, yet communication issues and delays means that up to 3 days may pass before all data is collected. There has been a few specific periods where data has not been collected due to communication breakdown. Hence, for most households the recorded power consumption is not entirely complete. . Consequently, the data must be sorted such that enough training, testing and validation data is available, while making sure to choose the days where most of the meters reported.
3. With the resulting training data, a neural network is trained, which takes as an input weather forecasts (e.g. ambient temperature, wind, solar irradiance) and temporal data (time of day, weekday, day of year, and holidays). The output is the expected aggregated power time series, as well as a confidence interval for the selected period.

4.2 Confidence intervals

The confidence interval can be defined through a x^{th} - percentile limit on a test data set. Test data sets are used in machine learning to test models, which were trained on a training data. The predictions of the trained model can then be evaluated on a test validation set and the prediction errors can be used to define the confidence intervals based on the x^{th} percentile.

5 Service Verification

5.1 Individual service verification

In EcoGrid 2.0 services are verified based on Smart Meter data, which are collected on a 15-minute basis. The total power consumption data of an aggregation can be retrieved with a delay of 12 hours after being recorded.

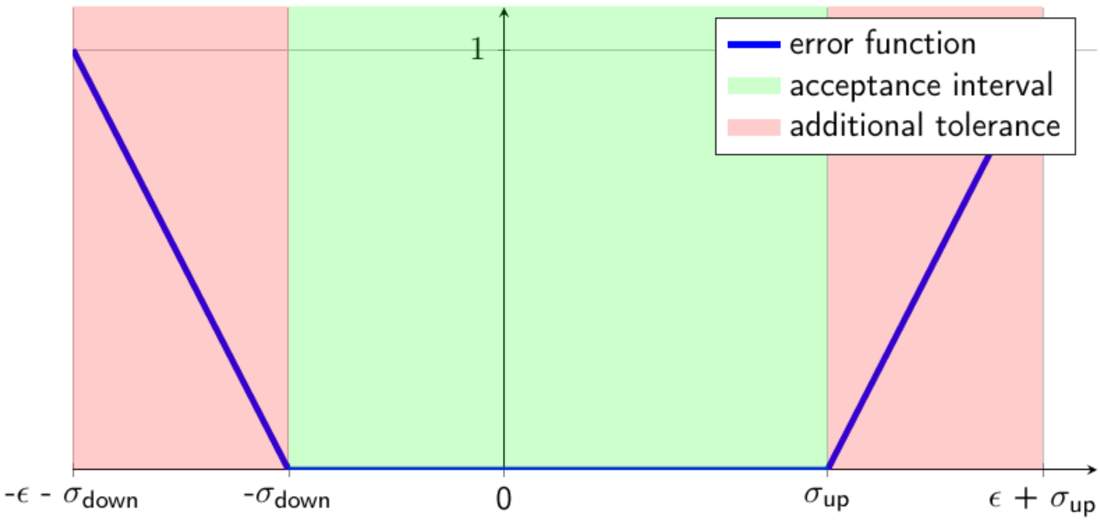

Figure 2: Error function f(x) mapping the deviation from the ideal response to a performance value

Figure 3 shows the defined error function $f(x)$ for service delivery verification. For every timestep of the service delivery period (response and rebound time) the deviation from the ideal response will be calculated. The total service performance will then be calculated as

$$\eta_{tot} = 1 - \left(\frac{1}{n}\sum_{i=1}^{n} f(P_{ideal} - P_i)\right).$$

If any of the measured values during the service hours lies outside the acceptance interval or the additional tolerance, the service performance will be equal to zero and service delivery will be considered failed ($\eta_{tot} = 0$).

The amount of compensation, that the aggregator receives for delivering the service, will be the nominal compensation offered for full delivery multiplied with the total service performance (η_{tot}).

5.2 Long term service verification

The confidence interval of the service specifications in Section 3 is defined through the load forecast of the aggregation. When delivering a service, aggregators are expected to regularly deviate from the defined "ideal service delivery", due to this uncertainty. As long as the total load stays within the acceptable interval, the aggregator is compensated fully. Theoretically, this tolerance gives aggregators an incentive to regularly under-deliver sold services. In the project, we introduce a second long-term verification, to counteract this incentive. This verification is applied to similar services (in terms of time and quantity), which an aggregator has been able to sell repeatedly. It is based on the fact that the distribution of the deviations from the ideal service delivery is supposed to resemble the prediction error distribution of the baseline, in the case that an aggregator delivered a service as promised.

Both the mean error as well as the standard deviation are calculated for the delivery hours of similar services of the past. The mean deviation from the defined ideal service delivery averaged over many service deliveries should be small and can otherwise indicate intentional under-delivery.

In EcoGrid 2.0 long term verification will only be applied to DSO-services. However, both the long term standard deviation as well as the long term mean error will be calculated for the delivered TSO services.

6 Bibliography

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