Smart TSO-DSO interaction schemes, market architectures and ICT Solutions for the integration of ancillary services from demand side management and distributed generation

Pilot B;

Challenges of Defining Direct (Scalar-based) or Indirect (Price-based) Control Signals for DERs to Access the Market Directly or Through Aggregators

Part 1: Description

Document for Consultation

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Acronyms

MO	Market Operator
AGG	Aggregator
DER	Distributed Energy Resource
TSO	Transmission System Operator
DSO	Distribution System Operator
RPM	Regulating Power Market
BRP	Balance Responsible Party

1. Introduction

The purpose of this document is to present an analysis framework for various control signals and market concepts in order to set an appropriate discussion about their advantages and challenges in Pilot B of the SmartNet Project. This part of the SmartNet project is progressing in the development of algorithms and digesting the actual implications of the control signals between the Market Operator (MO), the Aggregator (AGG), and the Distributed Energy Resources (DERs) in the pilot. This document, in the following: i) introduces different options of market design, e.g., to assess whether DERs will be acting in the markets directly (two-way communication) or through the AGG; and ii) discusses two different approaches for control signals: price-based and scalar-based.

2. Pilot B and the challenges of the Danish power system

The main purpose of Pilot B is to implement and evaluate the concept of model-based control principles for activation of flexibility from swimming pools to provide system balancing and grid congestion services at Transmission System Operator (TSOs) and Distribution System Operator (DSO) level. Summer houses have a relatively large and flexible consumption, e.g., the electrical load used to heat pool water can easily be shifted in time. This makes them particularly well-suited to the provision of ancillary services. In total, a living lab implementation of 30 summer houses will be established at two geographical areas in Denmark. The first group of houses (around 10) is installed in Blokhus in the northern part of Jutland, and the second group of houses (around 20) will be installed in Blåvand near Esbjerg. Both areas are covered by Syd Energi, a leading DSO in Denmark. The SmartNet Pilot B is perfectly tailored to the existing situation in Denmark. Today (first half of 2017), 45% of the power load is covered by wind power on average and it will increase in the future. The limited predictability of this fluctuating wind resource more often leads to imbalances. These imbalances in Denmark are, to a large extend, handled by the large thermal loads, inertia of the district heating systems, and balancing with neighboring countries. Most district heating systems have the possibility of using either boilers, heat pumps, or gas engines. They shift between these production units depending on the electricity prices.

An important technological advancement incorporated into Pilot B in SmartNet is the field test and proof of concept of DERs using unidirectional communications. In such unidirectional context, two different control mechanisms (direct, i.e., scalar-based or indirect, i.e., price-based) can be implemented in alternative. The former is a direct control signal requesting the DERs to turn on/off based on the optimization done at the AGG while the latter allow for the DERs to perform economic optimizations, and leaves leaves to the DER themselves the ultimate decision to get activated. Note that the pilot considers only the SmartNet Reserve Market and completely disregarding previous energy markets (Day-Ahead and Intraday). In Pilot B, the AGG acts also as Balance Responsible Party (BRP).

In the price-based indirect mechanism DERs, after receiving the control signals, calculate: i) the optimal consumption profile within the forecast horizon, and ii) the set-point for the thermostat of each individual summer house. This control signal is based on the grid load forecasts, the price forecasts, the weather forecasts, and the booking information. Measurements from the summer houses are afterwards collected and used, among other information, to feed price-responsiveness information in the price response model. Note that in this case, the AGG performs a different optimization, namely estimating the overall response and calculating the optimal price signal to be send based on the activated bids and the estimated response. The heterogeneous and stochastic nature of the responses of the DERs calls for new procedures for: i) predicting how to invoke the needed flexibility, and ii) characterizing and describing the relationship between control signals and the resulting electricity load. Following sections of this document provide more details on the framework outlined so far.

3. Concepts of market design and challenges of defining control signals

As already clarified, SmartNet Pilot B aims at performing an in-depth analysis and test of control of DERs. There are several solutions for activation of flexibility from DERs both on MO and AGG levels. Each of them holds advantages and challenges. In this document, we will discuss the advantages and challenges of indirect control through the AGG compared to three other solutions (Section 3.2-3.4). The adoption of the control-based approach using indirect control method turns the power system operation problem into a control problem where model of the system, devices, and services can be nonlinear, dynamic and stochastic. Concerning the control signals, two different approaches, namely **Price-based** and **Scalar-based**, are discussed. Both options share the feature of requiring just unidirectional signals from the AGG towards the flexible DERs ending up in a stochastic control for the DER assets. The section is concluded by a comparison table explaining advantages and challenges of different concepts of market design.

3.1. Indirect control through the AGG

Figure 1 shows the main communications among the actors defined in this concept. The price-based approach implements an indirect control consisting of a one-way communication from the AGG to the DERs, where the price signal is used to influence the whole load of the DER during the activation period. The MO, after clearing the market, sends market clearing information to the AGG. In turn, the AGG calculates the price-based control signal beside estimating the flexibility function. Such flexibility function aims at being able to predict the electricity demand as a function of prices. The purpose is to activate the flexibility of the DERs in the way, which creates most value for the DERs and the AGG during the next hours. Then, it broadcasts control signals to the DERs, prompting to a certain electricity consumption profile of the summer houses. These signals and the induced response may serve to reduce peak power consumption, or to increase power consumption in case of surplus of available power. This approach requires no feedback since it operates in an open-loop scheme.

Each DER, after receiving the signals within specific time resolution (for example 5 minutes), uses this information to plan the optimal consumption profile which results in the lowest electricity bill while staying within the boundary conditions, for instance pool temperature. Prior to reaching the next time step, the price for the next time step is sent from the AGG including an updated price forecast. Each DER updates its consumption profile for each time step. This results in a very simple unidirectional communication system and does not require commitment of the DERs. It lets the DERs optimize their consumption continuously. One challenge is, however, for the AGG to predict the response from the DERs at a given price signal.

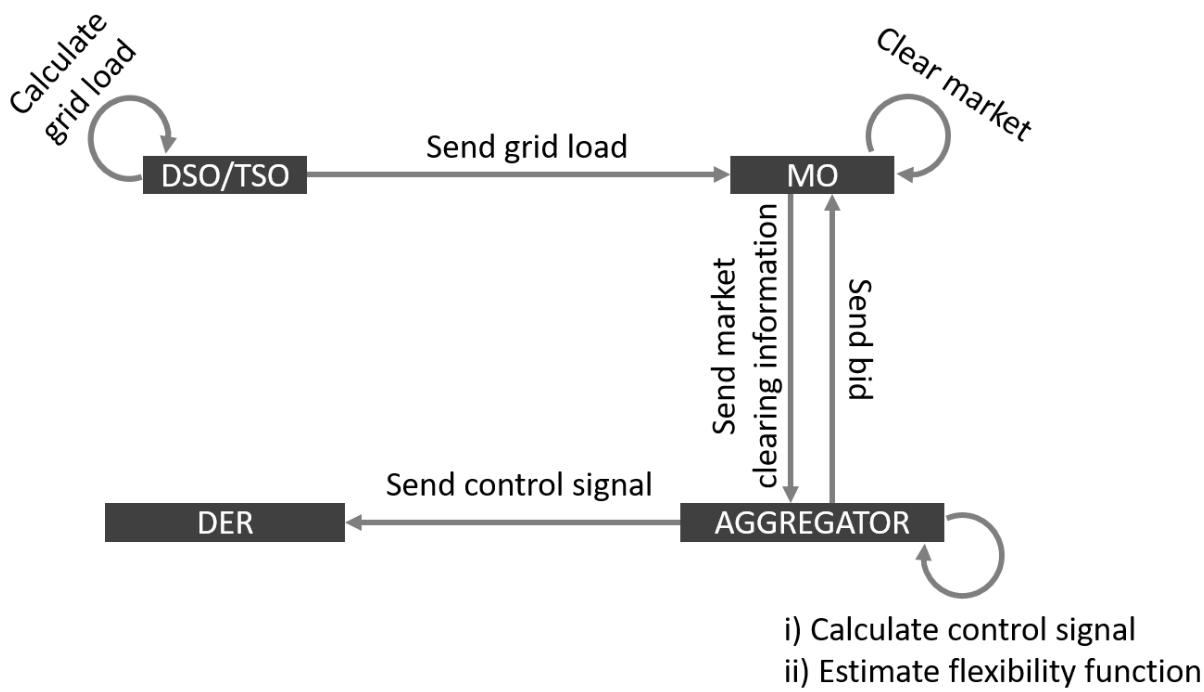

Figure 1: The main communications in controlling DERs indirectly through the AGG.

The AGG, by establishing a price generation mechanism, determines the optimal real-time price signal based on estimations of the aggregated response; the so-called flexibility function. Such estimations are based on historical data and the characteristics of the response can be tailored to specific needs. In IEA Annex 67 “Energy Flexible Buildings,” the authors for characterizing the aggregated flexibility response on a step-change in price use a step-response function as illustrated in Figure 2.

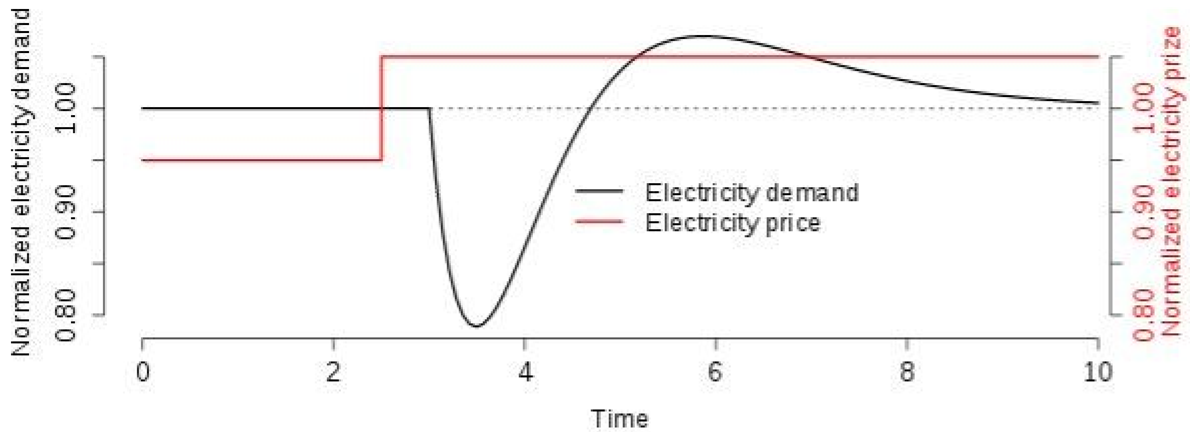

Figure 2: Example of a flexibility function. The aggregated response in electricity demand as a result of a step-change in price for a particular type of DERs

3.2. Indirect control from the MO

In the current Regulating Power Market[1] (RPM) up- or down- regulation is activated from a merit order list of bids. The price of the most expensive activated bid is the marginal price as in the Day Ahead Market. The marginal price will be paid for the activation of all the selected bids This price is currently not published until after time of operation. Yet if a large market player has put many bids on the RPM it is able to guess the market clearing price . This creates an inequality of information, which gives the large market players an advantage over the small ones. To publish the cost of imbalance from before time of operation would even out this inequality.

An alternative to control of DERs through an AGG is to have the MO publish the clearing cost of imbalance before time of operation and thereby let the DERs react on it, as Figure 3 illustrates its main communications. This is one version of price-based indirect control from MO. One challenge in this solution could be that market players will have less incentive to bid in the RPM because they could just wait and react to the imbalance cost afterwards. Therefore, this could remove liquidity from the RPM.

Instead, the MO could replace the RPM by an indirect control system and publish a price and a forecast designed to obtain balance. The price is set and frequently updated such that the system is in balance. To furthermore let DERs be settled directly at this price would give them the opportunity to optimize according to this price. This solution is similar to the solution proposed in Section 3.1. Nevertheless, the MO is broadcasting the price signal instead of the AGG. One advantage is that the MO has more system information available and hence should be better at estimating the response to a price. Furthermore, the relative prediction error is smaller for a large population of DERs. One challenge is that it is a completely different market design which could show some unexpected responses and that it leaves the balance responsibility at the MO.

[1] The RPM here is the Nordic regulating power market where the manual reserves are paid to deliver up- and down- regulation. It is often confused with the mFRR market which is a reserve market where capacity is procured to stand by for activation in the RPM.

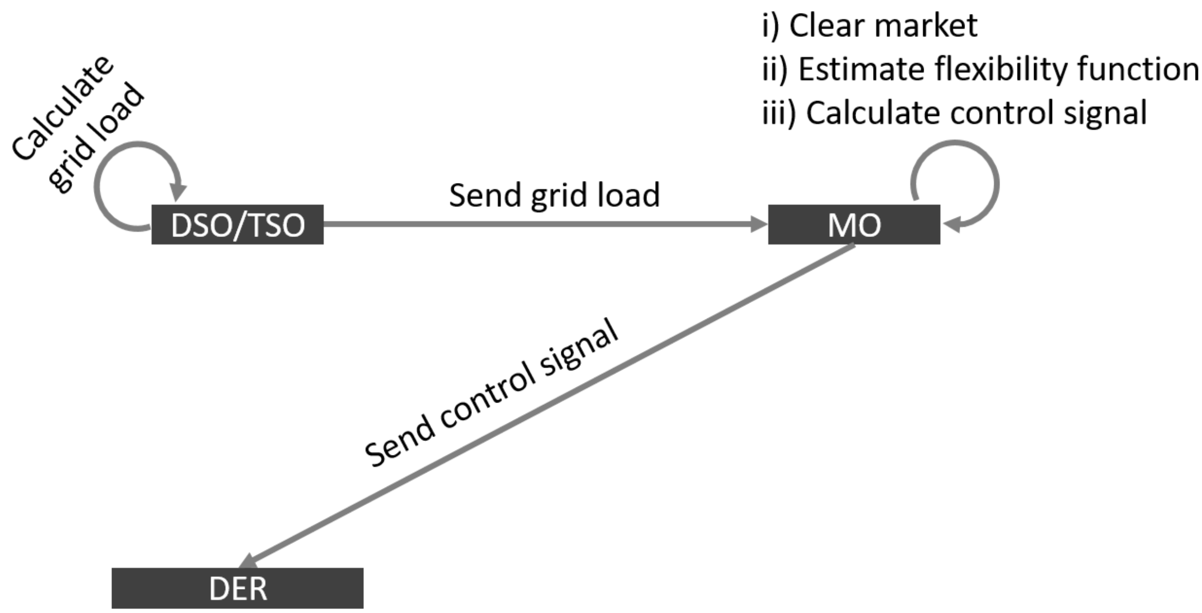

Figure 3: The main communications in controlling DERs indirectly through the MO.

3.3. Direct control through the AGG

An alternative to indirect control is direct control where the AGG does the optimization and directly controls the DERs remotely. There are multiple ways of controlling the DERs, but a typical method is by two way communication where the DERs send state variables to the AGG which does the optimization and sends back the consumption profile to the DERs. This is more demanding in terms of communication than price-based indirect control, but the response perhaps more predictable.

A different way is, inspired by price based control, by a unidirectional scalar-based control. This approach consists of the broadcast of a simple scalar x in a given scalar range (e.g., [0,1]), which is the sole piece of information interpreted by the stochastic control. The AGG, for bidding and clearing mechanisms, has an accurate model of the reaction and acquires firm commitment for a given volume and a given price towards the MO. This requires the AGG to carry out the optimization since the DERs are simply obeying a command from the AGG. This concept has the advantage of unidirectional and thus much simpler communication similar to the price-based indirect control, but the main challenge is to estimate the available flexibility without the real time information of the DERs. An additional challenge is to ensure that the DER is actually following the scalar control signal since it does not have an economic incentive to do so as in the case of price based control.

3.4. Direct control from the MO

This concept is to let DERs act directly in a transactional market. Here, it is named direct control because of the context to distinguish it from indirect control but it is sometimes described as a transactive energy system. The concept includes markets with lower barriers on, for example, minimum bid and transaction cost, as well as lower barriers on being a BRP. This may lead to millions of DERs being their own BRP and making automatic micro trading in the markets. Consumers can choose to have a separate BRP/AGG if this is more valuable to them.

Table 1: Comparison between advantages and challenges of different concepts of market design.

Approach	Mediator	Advantages	Challenges
Indirect	**AGG (Price-based)**	● Communication is simple and fast (requires neither a two-way communication, nor a computationally expensive market operation) ● Low control requirements for the DERs ● The risks can be calculated (since we can provide probabilistic statements about the response) ● Low entry barrier ● Scalable to millions of DERs ● Economic optimum for every single flexible DER in relation to the price signal. ● Data privacy ● Is expected to harvest the full flexibility ● Offers a cheaper solution in terms of implementation and regular maintenance costs ● DERs participate actively in the market	● Exact response to the prices unknown ● Estimation of the flexibility curve might be difficult
	MO (Price-based)	● Full use of flexibility potential ● Directly available same price for all DERs ● No contract needed ● No need to go through AGGs or BRPs ● The risks can be calculated ● Closer connection between market and consumer ● Very low transaction costs ● Data privacy	● Exact response to the price is unknown ● Less information about the near future load compared to current RPM (MO) ● Only suitable for close to real-time markets
Direct	**AGG (scalar-based)**	● Unique decision making by the AGG to manage the activations on behalf of the decentralized DERs	● Limited flexibility potential is activated ● Limited economic optimization of DERs in real time

		● No control obligation for the DER ● Low entry barrier ● Scalable to millions of DERs	● Exact response to control signal is unknown ● Uncertainty in having an optimal economic dispatch ● Less attractive to DERs to react upon signals if the consequence for them is not clear. ● No control possibility for the DER ● The implementation of e.g., smart Appliances is impossible or difficult ● Settlement only through either activations or capacity prices ● Risk that DERs will ignore control signal and the economical optimization according to other external parameters
	MO (Transactive)	● Full use of flexibility potential ● Balancing is solved in the market / response of DERs is known ● Bid optimization by MO	● Requires market development to lower barriers ● Large number of bids and trades requires more efficient market clearing algorithm ● More demanding for DERs to bid/activate than to react on control signal