SmartNet: Aggregator role

Document for the SmartNet Project Advisory Board

Due to an increase of variable, non-dispatchable Renewable Energy Sources (RES), predominantly based on wind and PV solar, flexibility is becoming a key need for the power systems. One of the key assumptions to be demonstrated by the SmartNet project is that such flexibility needs, to a certain extent, can be met by the Distributed Energy Resources (DERs), namely demand side management, distributed generation and storage. The flexibility coming from DERs has the potential to provide local services to the Distribution System Operator (DSO) as well as Ancillary Services (AS) to the Transmission System Operator (TSO). The novel market mechanism, the new coordination schemes between DSOs and TSOs, and the supporting distribution level ICT infrastructure can facilitate the flexibility provided by DERs.

The aggregator's role is to act on behalf of the service providers on the electricity market. In general, the aggregator's tasks are:

- determining the price and the quantity of individual bids,
- aggregation,
- disaggregation.

The aggregator uses the DERs mathematical models, which specify the physical and dynamic behavior of the resources, in order to accurately determine the amount of flexibility and its associated cost. The aggregator outputs the amount and price of ancillary service DERs are willing to provide, in the form of the market bids. The complex offers must take into account the dynamics and physical characteristics of the different DERs, provided by [1], whereby they are still simple enough so that they can be processed by the market-clearing algorithms described in [2]. Due to a larger number of DER units, which have a small flexibility capability, the aggregators play a key role, by reducing the amount of data passed onto the AS market. This data would otherwise congest the market clearing algorithm developed in [2]. The aggregators' role, besides aggregating the bids of the individual assets, is also disaggregation (sometimes also referred to as allocation). In terms of the power system's operation disaggregation would be most similar to the generation economic dispatch.

In the SmartNet project the individual DERs are classified into eight categories [1]: demand side management (shiftable and sheddable loads, as well as Thermostatically Controlled Loads (TCLs)), distributed generation (conventional, RES, Combined Heat and Power (CHP)) and storages (static, electric vehicles). However, when it comes to the aggregation process, the more distinct the features of the aggregated devices are, the less accurate the approximations can become during their aggregation and the more difficulties can arise during the disaggregation stage. Therefore, for the aggregation purposes, these DERs categories are grouped, based on the modeling similarities, into five aggregation models:

- Atomic Loads,
- CHP,
- Curtailable Generation and Sheddable Loads,
- Storages,
- TCLs.

As the market clearing mechanism is able to cope with multiple bids originating from the same aggregator [2], the simplest approach is for the aggregator to allow all five aggregation-type-specific categories, mentioned above, to generate bids for their own aggregated devices. By doing so, every bid that gets accepted by the market can then be assigned to the corresponding device-type-specific disaggregation algorithm, which is best equipped for optimally distributing the allocated flexibility over its individual devices. By doing so there is no need to build an overarching aggregation model, as such a model would inevitably make disaggregation cumbersome.

In the literature, there are several different aggregation approaches used for bidding in the electricity market:

- physical (bottom-up),
- traces
- data driven,
- hybrid.

Each aggregation approach has certain advantages – either by the amount of required data, or the accuracy aspect of the modelled portfolio, which are discussed below.

The physical (bottom-up) approach [3], [4] uses the horizontal summation [5], [6] of power calculated for the individual devices. In this approach, it is assumed that the aggregator knows all of the parameters of each individual device and also its real time status. In [3] physical entities, including onsite generation, storage systems, load curtailment and load shifting, are modelled as aggregated bids and applied in a problem of constrained optimization. The bottom-up approach intends to study the adoption of DERs from the perspective of the physical entities, including the constraints and technical peculiarities for each technology. The physical approach can potentially become difficult to implement when many heterogeneous energy resources are included. In fact, different values and constraints have to be defined and represented in the model, where the approximation of generic values might not accurately represent the modeled DERs' portfolio. The advantage of this approach is that the disaggregation is straightforward.

The traces approach shares similarities with the physical bottom-up approach. The exception is that it is characterized by load profiles and the cost associated to each of the profiles, and not by the exact physical DERs' characteristics due to, e.g. confidentiality reasons, prohibitive complexity or insufficient accuracy of the available models. The aggregation is represented by all the possible combinations of feasible profiles of all the devices. The particular advantage of this approach, the same as for the bottom-up approach, is that the disaggregation is also straightforward. When a bid is formed from a particular combination of the feasible device profiles and the bid is cleared, allocation of feasible profiles to every aggregated device simply means allocation of profiles corresponding to that combination.

The data driven approach [7]-[9] is based on data and intends to emulate the behavior of a pool of devices. Here, the physical entity and the specific technology is not considered anymore, as the behavior of the whole pool is analyzed. For this approach, the availability of good-quality data is fundamental. Alternatively, the data needs to be simulated. In [8] and [9] the data-driven approach is applied for predicting the optimal bidding schedule. The data-driven approach does not require any reference value taken from literature, since it is built by using a more accurate level of information. Due to this reason, it needs more input data than the physical approach, which can be problematic in case of data scarcity. This is why this aggregation approach is not used in SmartNet, since the consumption data, correlating to the electricity price, is still nonexistent for most of the DERs considered in this project. Opposed to the physical approach, which needs to have the aggregated values and parameters properly estimated, in the data-driven approach the parameters estimation comes from the data.

The hybrid approach [10]-[12] uses a single, or a limited number of virtual devices in order to represent the entire population of aggregated devices. Such practice reduces the number of individual devices and avoids exhaustive bid parametrization. Hence it can be argued that in the case when a really high number of devices needs to be aggregated the hybrid model is a reasonable approach. The drawback of this approach is that it requires a disaggregation model, in order to allocate flexibility to individual devices. It is also a fact that in the case of heterogeneous devices, the hybrid approach introduces a modeling error. A way to reduce this error is to cluster the devices that have similar model parameters, such that there are homogeneous devices in each cluster. A potential algorithm for clustering of the individual devices is the *k*-mean algorithm [13], [14]. As the number of clusters increases, the hybrid approach becomes closer to the bottom-up approach. In the case when the number of clusters equals the number of individual devices, the hybrid approach becomes the physical, bottom-up, approach.

Table 1 Overview of different aggregation approaches for DERs

Aggregation approach	Literature	Disaggregation
Physical	[3], [4]	Straightforward
Traces	-	Straightforward
Data-driven	[7], [8], [9]	Model
Hybrid	[10], [11], [12]	Model

The bottom-up approach was selected as the preferred option due to the lower number of devices which are being aggregated at each MV node. The number of devices is higher when aggregating at the transmission level node, making the bottom-up approach cumbersome. The aggregation is done at each MV distribution level node separately. By choosing the bottom-up physical approach, disaggregation is straightforward, since the devices which bid with price lower than the market clearing price are the only ones being activated. This makes disaggregation models superfluous.

Although, the bottom-up approach was selected as the preferred option, as explained above, other aggregation approaches were used in some of the models due to physical characteristics of the aggregated devices, the number of the individual devices being aggregated and the availability of data. This is summarized in the table below.

Table 2 Aggregation approaches used for aggregation of different DERs

Models	Aggregation approach
Atomic Loads	• Traces
CHP	• Physical
TCL	• Physical • Hybrid
Storage	• Physical
Curtailable generation and sheddable loads	• Physical

References:

[1] AIT, RSE, and N-SIDE "Characterization of flexible resources and distribution networks," SmartNet project, Deliverable D1.2 - draft version, Dec. 2016.

[2] N-SIDE and VITO, "Market Design for Centralized Coordination Mechanism," SmartNet project, Deliverable D2.4 - draft version, Oct. 2016.

[3] S. Ø. Ottesen, A. Tomasgard, and S. E. Fleten, "Prosumer bidding and scheduling in electricity markets," *Energy*, vol. 94, pp. 828-843, Jan. 2016.

[4] M. Parvania, M. Fotuhi-Firuzabad, and M. Shahidehpour, "Optimal Demand Response Aggregation in Wholesale Electricity Markets," *IEEE Transactions on Smart Grid*, vol. 4, no. 4, pp. 1957-1965, Dec. 2013.

[5] M. Gonzalez Vaya, "Optimizing the electricity demand of electric vehicles: creating value through flexibility," PhD thesis, ETH Zurich, 2015.

[6] G. Petretto et al., "Representative distribution network models for assessing the role of active distribution systems in bulk ancillary services markets," *2016 Power Systems Computation Conference (PSCC)*, Genoa, 2016, pp. 1-7.

[7] O. Corradi, H. Ochsenfeld, H. Madsen and P. Pinson, "Controlling Electricity Consumption by Forecasting its Response to Varying Prices," *IEEE Transactions on Power Systems*, vol. 28, no. 1, pp. 421-429, Feb. 2013.

[8] J. Saez-Gallego, J. M. Morales, M. Zugno, and H. Madsen, "A Data-Driven Bidding Model for a Cluster of Price-Responsive Consumers of Electricity," *IEEE Transactions on Power Systems*, vol. 31, no. 6, pp. 5001-5011, Nov. 2016.

[9] J. Saez-Gallego and J. M. Morales, "Short-term Forecasting of Price-responsive Loads Using Inverse Optimization". Available at: https://arxiv.org/abs/1607.07209.

[10] N. Ruiz, B. Claessens, J. Jimeno, J. A. López, and D. Six, “Residential load forecasting under a demand response program based on economic incentives,” *Int. Trans. Electr. Energ. Syst.*, vol. 25, no. 8, pp. 1436–1451, Aug. 2015.

[11] P. Koponen et al., "Toolbox for aggregator of flexible demand," 2012 *IEEE International Energy Conference and Exhibition (ENERGYCON)*, Florence, 2012, pp. 623-628.

[12] S. Iacovella; F. Ruelens; P. Vingerhoets; B. Claessens; G. Deconinck, "Cluster Control of Heterogeneous Thermostatically Controlled Loads Using Tracer Devices," *IEEE Transactions on Smart Grid*, vol.PP, no.99, pp.1-9.

[13] W. Zhang, K. Kalsi, J. Fuller, M. Elizondo and D. Chassin, "Aggregate model for heterogeneous thermostatically controlled loads with demand response," 2012 *IEEE Power and Energy Society General Meeting*, San Diego, CA, 2012, pp. 1-8.

[14] W. Zhang, J. Lian, C. Y. Chang, and K. Kalsi, “Aggregated Modeling and Control of Air Conditioning Loads for Demand Response," *IEEE Transactions on Power Systems*, vol. 28, no. 4, pp. 4655-4664, Nov. 2013.