Towards Interoperability of Energy Management Systems using Flexibility through Conceptual Modeling

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***Abstract*—Smart Grid technologies are being developed to better operate the power system and integrate larger amounts of renewable intermittent power sources and new energy efficient electrical equipment. Coordinating flexibilities in power supply and demand plays a crucial role in this development. Interoperability between actors and their systems is of importance for the efficient and cost effective operation and adoption of Smart Grid technologies. Many technologies exist that address this subject. In this paper an overview of existing technologies is given and a classification for understanding these technologies is provided. Moreover and most importantly an overarching conceptual model is outlined as a basis for interoperability on the semantic level, an important first step towards overall interoperability.**

I. Introduction

Use of renewable energy sources and more efficient use of energy is enforced by national and international regulations, see e.g. [1] and [2]. Due to the intermittent character of renewable energy sources such as photovoltaic or wind power, and characteristics of efficient technologies such as in electric mobility and electric heating, integration of such technologies creates a challenge in maintaining balance between demand and supply as well as the correct and efficient operations of the power system in general.

Smart Grid technologies are being developed in order to better operate the power system and integrate larger amounts of renewable intermittent power sources and new energy efficient electrical equipment. The use of flexibilities in power supply and demand – the ability to adapt the usage or production of electricity – and related Smart Grid communications plays a crucial role in this development.

Interoperation between actors and systems in the Smart Grid is a key aspect in its efficient and cost effective operation. This is of equal importance to actors and systems involved in leveraging supply/demand flexibilities, and moreover, interoperability will most likely support the deployment of such systems and relevant business models.

In [3] a conceptualization is provided of a specific technology – developed in the European FP7 research project Mirabel – for trade in flexibilities in power supply and demand. However, many technologies currently exist which are designed to also leverage flexibilities in power supply and demand.

In this paper, a broad scope of existing technologies is surveyed in order to 1) build an understanding of these technologies, 2) provide an identification of commonalities and differences between them, and finally 3) a conceptualization of the reviewed technologies as an important basis for interoperable systems leveraging power supply and demand flexibility.

In interoperability in Smart Grid systems, many aspects need to be covered as described in the GridWise Interoperability Context-Setting Framework [4]. The main research question addressed in this paper is how to develop the semantic understanding related to flexibilities in power supply and demand as a basis for technical interoperability as well as informational and organizational interoperability. In order to complete our approach further research should provide an implementation or simulation of the proposed conceptual model.

In this paper, the context of using flexibilities is outlined in Section II. Given this context an overview of existing technologies is provided in Section III, continuing with a classification of all these technologies. In Section IV, the main part of this article, a conceptual model is described based on the surveyed technologies. Finally, Section V provides a summary and an outlook on future work.

II. Role model and flexibility usage

In order to understand the technologies reviewed in this paper this section provides a context by describing an abstract role model; this model is shown in Fig. 1.

We discern between operators of flexibility with flexibilities in their operation of power supplying and demanding resources (equipment) with flexibilities in their operation, operators of this flexibility, and users of this flexibility which need to influence (in some form) how the flexibility is

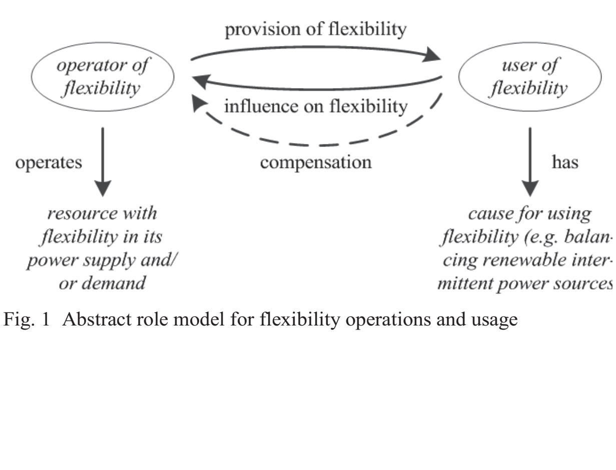

Fig. 1 Abstract role model for flexibility operations and usage

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operated, e.g. to operate a grid within its limits, balance supply and demand, etc.

With regard to a better understanding of the coordination technologies surveyed in this paper we first here provide an overview of resources that are operated and which provide the wanted flexibility. From [24] we have:

- Resources with operations with a deadline: resources for which a certain process needs to be completed before a certain deadline. Example include (domestic or industrial) washing, drying processes, to certain extent charging an electric vehicle, assimilation lights in greenhouses and ventilation systems in utility buildings.
- Buffering resources: resources which in their operations depend on a buffering of something other than electricity. Examples include heating or cooling processes with e.g. combined heat and power installations or heat pumps, whose operation objective is to keep a certain temperature within an upper and lower limit.
- Storage: resources capable of storing energy based electricity use which can later be used to supply power back. Examples include conventional batteries, flywheels and super-capacitors.
- Freely-controllable generators: resources which have generation of electricity as their primary function (e.g. diesel generators).

The coordination technologies identified in this paper mainly focus on the coordination of supply of and demand for electricity in terms of volumes of real energy. That is, a supply of or demand for a volume of real energy within a certain period. This corresponds to mean active power supplied or drawn for that period. Some of the surveyed technologies also directly coordinate active power levels. There are a few other technologies which receive mostly little attention including: reactive power, ramping rates and ancillary services such as frequency controlled supply or demand.

Various goals can be identified in the documentation surveyed in this paper. The most common ones include:

- Avoiding overloading of grid components (congestion)
- Ensuring power quality levels within limits (e.g. on voltage levels, transients, harmonics)
- Maintaining a balance between demand and supply, including:
  - Avoiding shortage of supply (overloading generation)
  - Avoiding fast ‘ramp-up’ of load which can’t be followed by generation
- Increasing efficiency, including:
  - Reducing the amount by which generation needs to ramp up and down
  - Reducing the amount of peak generation capacity (e.g. by peak-shaving)
- Optimizing a commercial position, e.g. by improving positions in ‘intraday markets’ and/or in relation to imbalance penalties or payments

III. Classification

Many different research and industrial activities have developed technologies for coordinating supply and demand. Based on a fairly large number (15) of technologies identified: Address [5], AIM [6], BEMI[1] [7], BeyWatch [8], EcoGrid [9], MeRegio [10], Mirabel [11], OASIS Energy Interoperation [12], OASIS emIX[2] [13], OpenADR 1.0 [14], OSGP[3] [15], PNNL[4] [16], PowerMatcher [17], Web2Energy [18], and ZigBee SEP[5] [19] we are now able to name a number of commonalities, i.e. categories, among these technologies.

The scope of this paper limits to technologies for coordination which are oriented towards market like environments with actors which have financial motives. Hence e.g. technologies for controlling assets within the scope of an organization[6] were not considered.

Below we give a description of these categories together with a count of the number of technologies found in each category:

Category	Technology count
• Direct control	5
• Ceilings and budgets	3
• Dynamic tariffs	11
• Events and programs	3
• Market based	3
• Flexibility products	2

A. Direct control

The direct control of flexible load and generation is of course something operational already for many years, i.e. in the control of power plants and to some extent (large) loads which play an important role (because of their size) in the operations of the power system.

The main characteristic of this type of control is that the coordination is based on influencing parameters (set points) which are on a very ‘low level of abstraction’. That is, very closely related to the actual characteristics of devices. This in contrast to many of the other categories of coordination which use abstractions such as volume of energy and tariff. Examples of directly controlled parameters are e.g. temperature set points or cycling air conditioners[7] and fine grained control of distributed energy resources[8]. In general it can be expected that direct control coordination is performed under a commercial or regulatory framework. For example by participating in a demand response program or because its enforced by law to ensure a stable and secure power system.

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[1] Bidirectional Energy Management Interface

[2] Energy Market Information Exchange, which is used as a basis for OASIS Energy Interoperation as well.

[3] Open Smart Grid Protocol, developed by Echelon and distributed by ETSI as ETSI GS OSG 001 early 2012.

[4] Pacific Northwest National Laboratory and their activities related to transactive markets in the Pacific Northwest Smart Grid project.

[5] Smart Energy Profile, this is a profile from the ZigBee alliance co-developed with the HomePlug alliance.

[6] With e.g. IEC 61850-7-420

[7] As e.g. performed by PG&E, ConEd and others, see e.g. http://www.pge-smartac.com and http://www.conedprograms.com

[8] E.g. by communicating ramping possibilities, detailed generation schedules, etc.

B. *Ceilings and budgets*

Ceilings and budgets set (administrative) limits to volumes of energy used (and theoretically provided) and power levels. Beyond such a threshold, either a financial action is taken, or even connection cut-off options are provides[9].

This category of coordination methods seems to be mainly used as either a means to prevent overloading in critical situations, or to implement pre-paid energy services. Actual adoption of this type of coordination seems very limited apart from the application of administrative power level ceilings for larger and industrial customers. However, this is arranged through contracts and enforced through metering systems.

C. *Dynamic tariffs*

Dynamic tariffing – in all its variations – is receiving much attention throughout the industry, in technology development as well as research. Methods in this category range from announcing a peak tariff in emergency situations to changing the tariff every 5 minutes.

Dynamic tariffing is reasonably simple, however increasing the dynamicity most likely reduces the ease with which this method is rolled out[10]. Transparency of tariffs of course requires much attention, in particular there needs to be a basis for the tariffs which is accepted by customers.

D. *Events and programs*

Event based demand response programs are well known for some years. Basically, the concept of these methods is to emit an event to the participants in the program requesting a certain behavior, mostly a load reduction. Some identified methods allow for more complex structures wherein participants can compete in who will implement the response (and receive compensation). Current deployments of this type of coordination seems to focused mostly on day-ahead and intraday (up to around an hour ahead in some cases) timescale. More near-real time coordination with this method is not known.

E. *Market based*

The identified market based coordination technologies apply concepts from market places such as bidding and equilibrium price to a new scale of deployment, i.e. much more and much smaller participants. An advantage in comparison to, for example, dynamic tariffing is that what the behavior of the participants will be, is much better known, because they are expressing their flexibility in terms of bids.

F. *Flexibility products*

This category of coordination technologies revolves around making flexibility in load and/or generation fairly explicit, although still in terms of energy/power, time and price (in contrast to some of the direct control methods such as through IEC 61850-7-420 for DER control). This type of coordination forms a hybrid method, drawing from elements in market based, event based as well as direct control coordination methods. This category of coordination is also fairly new and must be considered to be in a research stage.

TABLE 2 Mapping of coordination technology categories to packages of concepts in the conceptual model

	Time	Energy	Control	Finance	Negotiation
Direct control	×	×	×		
Ceilings and budgets	×	×	×	×	
Dynamic tariffs	×	×		×	
Events and programs	×	×	×	×	×
Market based	×	×		×	×
Flexibility products	×	×	×	×	×

IV. Conceptual Model

In this section we synthesize an overview of a key elements in a conceptual model based on specifications of the coordination technologies surveyed, through a clustering of concepts in packages. The five packages identified pertain to 1) time, 2) energy, 3) control, 4) finance, and 5) negotiation related concepts. Below, we will describe in sub sections these (packages of) concepts together with references to possible sources for further formalization and implementation of the conceptual model.

And also we denoted an overview of our categories of coordination technologies (Section III) in relation to the aforementioned (packages of) concepts in the conceptual model, see Table 2.

A. *Time related concepts*

Essential for the specification of many of technologies surveyed are concepts related to time. The most prominently concepts found were: 1) Absolute and relative *points in time*, 2) Periods of time or intervals and repetitions thereof, and 3) *Constraints* on points or periods in time Modeling of time naturally transcends the scope of the energy domain, and here standards such as ISO 8601 [20] can be used, also WS-Calendar [22] provides support for time related concepts; however concepts such as temporal constraints aren't supported.

B. *Energy related concepts*

A second package of concepts fundamental for methods of coordinating power supply and demand of course relate to energy concepts. Standards such as the Common Information Model of the IEC [21] but also OASIS's emIX [13] provides broad support for these concepts.

Most important in this package are measurable units related to electricity such as: *real energy*, *active* and *reactive power*, *ramping*[11]. It must be noted that most of the surveyed technologies only use the concepts real energy and active power from the energy related concepts. These concepts are also used relatively to a *baseline*. Apart from these measurable units, the notion of *energy resources* (equipment), groupings thereof into *scopes of responsibility* (domains of actors, e.g. a household) and their interconnections are found to be of importance in supply and demand coordination. Coordination

9 E.g. in the Open Smart Grid Protocol.

10 Experiments such as in EcoGrid, Web 2 Energy, MeRegio, etc. and comparison of their results will hopefully provide more insights herein.

11 I.e. the second time derivative of energy.

technologies in the ceilings and budgets, dynamic tariff and events and programs categories have this as an implicit notion, i.e. the information sent – such as a tariff – applies to the receiver. Direct control, market based and flexibility product technologies do have an explicit notion of either resources (e.g. a DER installation) or scopes of responsibilities (e.g. a bidding party responsible for energy delivery).

C. Control related concepts

Naturally, the technologies in the direct control category rely on concepts in this package, but also the category of flexibility products based coordination technologies use concepts in this package.

The most prominent concept here is that of a *set point* for a certain measurable quantity, possibly varying over time (i.e. a schedule). As described already in part A of Section IV, direct control technologies and the related concepts differ the most from other technologies and concepts. This will be taken into account in further study.

D. Finance related concepts

As this paper focuses on coordination of demand and supply in Smart Grids interoperation between actors and their systems, finance related concepts are also of importance in the surveyed technologies. Notable concepts are *price* and *tariff* and constraints thereon. Note that tariffs are not limited to monetary amounts per *volume of energy* delivered in the surveyed technologies, but also cover tariffs for capacities (i.e. the ability to supply or demand). Furthermore tariffs may be dependent on many aspects such as absolute time, relative time, energy flow over a period, etc.

E. Negotiation related concepts

In the more 'advanced' categories of technologies for coordinating supply and demand, negotiation related concepts play an important role. Most importantly the concepts, *tradable object*, *offer*, *request* and *agreement* provide an underpinning for actors interacting on a supply and demand coordination setting.

Furthermore, concepts are provided which support the flexibility based products: *options* and their *constraints*. In essence the flexibility based products define an option to ensure a certain measurable quantity.

V. SUMMARY AND FUTURE WORK

In this paper an overview of a broad spectrum of existing technologies for coordinating power supply and demand has been given. An initial categorization and conceptual model have been provided to aid in their understanding, their commonalities and their differences; a crucial step towards interoperability on the semantic level between actors and their systems involved in coordination of power supply and demand.

Future work includes further detailing and formalization of the conceptual model. This will provide a further step towards interoperability, also in other categories such as on the syntactic and business context level. Finally, the proposed conceptual approach should be quantitatively underlined with a performance evaluation of implemented or simulated models. We strongly believe that further investigation of the outlined conceptual model provides a promising element in the development of an interoperable, flexible and open energy management framework supporting a variety of applications coordinating supply and demand.

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