Semantic alignment in monitoring and verification of energy savings achieved by demand response flexibility programs

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***Abstract* - Smart grids and systems envision systematic integration of flexibility achieved through demand response programs at end-users' premises. Particularly interesting is the flexibility achieved from heterogenous sources such as residential consumers. Aggregators are expected to collect the flexibility from the residential consumers under contractual conditions and offer the aggregated flexibility by providing ancillary services to balance responsible parties. Additionally, aggregators of flexibility are expected to deliver flexibility programs rules (notification prior to a flexibility event, eligibility, rewards, penalties) respectively aligned with operating conditions, perform planning and forecasting of demand response flexibility and determine effectiveness of flexibility programs. The flexibility programs could also result in permanent energy savings which must be properly assessed. Monitoring and verification for demand response are imperative to determine demand reduction quantities in the context of settlement and impact estimation.**

Communication and information technologies incorporated into flexibility programs should allow real-time telemetry and event driven information of realized active demand response by remote control over specific customer equipment (flexibility assets). Load reductions achieved through the flexibility programs are not capable of being directly metered or observed. However, communication and information technologies should be capable of registering such event and such information should be properly identified. This paper analyses the capability for monitoring and verification of demand response of commonly adopted communication protocols (i.e OpenADR Open Automated Demand Response) and addresses the needs for proper semantic alignments. Such communication standards should have the ability for direct load control program accomplishment. For the demand response value chain to be fully functional, the paper also discusses the requirements for semantic interoperability among the above-mentioned entities.

Keywords - aggregators, communication and information technologies, communication protocol, semantic flexibility, monitoring and verification, semantic alignment

I. Introduction

The Clean energy package [1] is empowering the final energy consumers as crucial stakeholders in the energy transition. Even if regulatory and legislative changes are usually happening more slowly then the technological ones, the overall intention at EU level and beyond, is to integrate final energy consumers as active participants of future smart energy systems. Obviously, it is not expected that each final consumer will neither be capable of trading his self-produced electrical energy nor flexibility. Integrating distributed generation and flexible demand, delivered by final consumers heterogenous sources, requires innovative solutions and adequate regulatory frameworks [2].

For such reasons aggregators, as intermediaries, should enable citizen/consumers active participation in energy or ancillary service markets. Nowadays, the aggregators are mostly facilitating industrial and commercial consumers participation in such markets. This is happening for such facilities are equipped with proper: communication and information technology, historical data with appropriate resolution, real-time control, and data acquisition systems. All the mentioned benefits enable the establishment of proper settlement programs and impact estimations for the aggregator. Such terms are widely used in monitoring and verification programs for demand response (DR) and will be further clarified in this paper.

Setting-up innovative solutions for delivering demand response flexibility from residential consumers is becoming a trending topic of various research. Mostly, the activation of flexibility from residential consumers is envisioned as a response to a third-party request, such as distribution system operator (DSO) [3,4], or in response to local energy market signals [5,6]. Certainly, based on the received requests in conjunction with limits sets both by the program users and the aggregator, optimization objectives are evolving.

This paper is dedicated to the remuneration of energy savings, as part, or a goal, of a demand side flexibility program design for residential consumers. To ensure proper monitoring and verification of such obtained savings, explicit demand response should be applied. Explicit demand response implies direct control over a consumer load or via a home gateway, the application of proper information and communication technology, alongside with appropriate data storage and control architecture for enabling end-users demand response flexibility [7]. In other words, to activate flexibility, the controllable resources (loads) need to receive and execute commands from the aggregator. Controllable loads, capable of changing their set point (e.g., temperature), thus reduce their baseline load over a specified period of time while taking into account minimal impact to the user's comfort, are eligible resources for achieving energy savings. The baseline load could be described as the amount of energy the customer would have consumed in absence of DR signals for load reduction [10]. An example of such loads are heat pumps (HP) or air-conditioning (AC) systems [9].

While explicit demand response is mainly about shifting, shedding, and arbitraging consumption to a different point in time, the aim of obtaining energy savings triggered by DR signals to increase energy efficiency is to use less energy while still providing the same service or level of comfort. As could be seen in Figure 1, the remuneration of energy savings obtained by load reductions is particularly challenging because it is not possible to meter or otherwise directly observe load reduction [8]. For obtaining and calculating such achieved load reductions, monitoring and verification techniques used for energy efficiency analysis and communication protocols with semantical alignment should be properly applied. This paper, after providing an overview of rules and techniques used for monitoring and verification (M&V) of demand response, analyses the capability for M&V of commonly adopted communication protocols, outlines the needs for proper semantic alignments and finally discusses the requirements for semantic interoperability between involved entities.

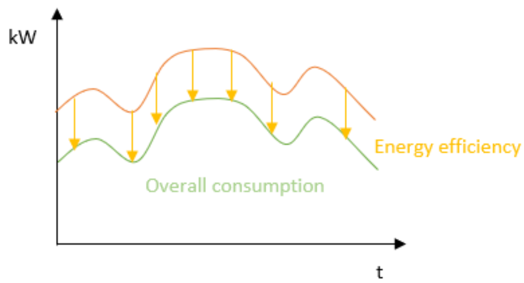

Figure 1. Reduction from baseline example

II. MONITORING AND VERIFICATION OF DEMAND RESPONSE RATIONALE

Measurement and verification of demand response flexibility, means the determination of demand reduction quantities in two broad contexts [8]:

1. Settlement – determination of demand reductions achieved by individual program or market participants, and the corresponding rewards or penalties allocated to or from each participant.
2. Impact estimation – determination of program level demand reduction that has been obtained or it is projected to be achieved, used for program evaluation and planning.

It is envisioned that the measured reductions should be recognized in both the contexts to ensure proper flexibility program design and its continuous verification during operation. Settlements should be considered in program planning, design and operation while impact estimation should examine the appropriateness and evaluate the program effects. M&V should ensure continuous program calibration and impact estimation.

Additionally, for M&V purposes it is important to understand the difference between ex-ante and ex-post impact estimates. The ex-ante impact estimation assesses and somehow forecasts future load reduction capabilities, while ex-post impact estimation assesses demand reductions retrospectively.

If the demand response program is based on "reduction from baseline" such baseline should be properly estimated. There are several methods for baseline load estimation, and each one is subject to some error. This paper does not discuss the estimation methods, but instead studies the capability of existing communication protocols to offer different opportunities for program settlement and impact estimation. Communication protocols and data models with proper message payloads should enable a comparative analysis of ex-ante impact estimates and ex-post analysis as an iterative process and continuous program adaptation (Figure 2).

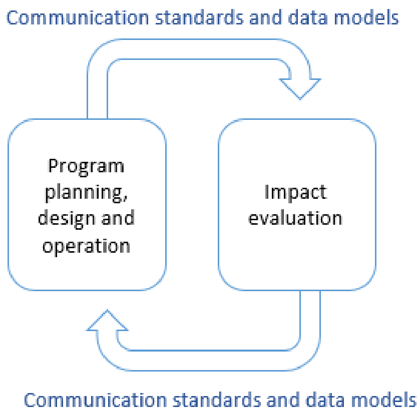

Figure 2. Iterative process of continous program adaptation

III. METHODOLOGY: EXISTING DATA MODELS, FORMAT AND STANDARDS ANALYSIS

This part is dedicated to the analysis of existing communication standards and data models capable of providing added value in the iterative demand response monitoring and verification process. The objective of this analysis is to scrutinize and select specific data models which are adequate for M&V purposes. Initially, based on the literature analyses a first screening on the state-of-the-art data models review which involved 40 different standards and ontologies was listed. This scrutiny evolved from current achievements from EU funded project dealing with flexibility, such as DELTA (Project No 773960 [11]), FLEXCoop (No 401790 [12]), HOLISDER (Project No 76861 [13]) and BEYOND (Project No 957020 [14]). Each data model was classified according to the entity of application (aggregator, consumer/prosumer), data model type (communication standard, communication standard with interpretation, building information model or ontology) and scope of application (demand response in buildings, machine-to-machine communication, building data model representation and business synergies and data exchanges between different stakeholders).

When roperly analyzed; several data models were identified as supportive for M&V purposes.

A. OpenADR (IEC 62746)

The most representative standard of the IEC 62746 family of standards, is IEC 62746-10: Open Automated Demand Response (OpenADR 2.0b Profile Specification) [15]. It represents the adoption of the OpenADR Alliance standard as an IEC standard. The IEC 62746, as a flexible data model enables: common information exchange between electricity service providers, aggregators, and end users. Furthermore, its open specification facilitates anyone to implement the two-way signaling systems: providing the servers that publish information to the automated clients subscribing to the information. Such information can serve as immediate verification of curtailment and identification of failed or over-ridden signals [8].

More pragmatically, in its purpose, this standard covers the demand response value chain; a smart grid flexibility activator (i.e. aggregator) and a smart home flexibility resources. It also provides application-level service communication, which can be used to incentivize responses from the customer-owned and customer-located distributed energy resources.

In the framework of IEC 62746, the following services are specified:

- *Register*: identification of entities (prior to the interaction with other parties);
- *Event:* providing event functions and information models for price-responsive demand response;
- *Report:* provides feedback either periodic or one-time information on the actual state of a resource.

Moreover, IEC 62746 is capable to address short-term changes in availability - provide opt-in and opt-out schedules from virtual end nodes to virtual top nodes [16]. The opt-in and opt-out options are a key difference to classic telecontrol protocols where traditionally only technical unavailability is implemented.

As described above, the OpenADR standard specifies the data semantics only to a limited extent. The message payload interpretation does not go beyond the generic types of events.

Even though this standard finds its application in a considerable amount of demand response solutions, it provides minimal extent of a data model for demand response, pricing, distributed energy resources (DER) communication and facilitates information exchange between electricity service providers, aggregators, and end users. This standard supports also direct load control interactions which is binding for explicit demand response. Nevertheless, it only provides the DR message exchange and none of the actual underlying application logic. For monitoring and verification of DR purposes, OpenADR is applicable but needs to be enhanced with additional data semantics alignments. When the customer is paid based on the participation metrics, OpenADR is suitable for verification of such events. However, *Event* and *Report* services are not enough for impact estimation, nor payload messages are describing the assets involved in direct load control events and the interrelationship between them.

B. IEC 61850

While investigating M&V applicable standards, the IEC 61850 cannot be avoided whereas it is practically the most utilized common standard in the electrical power engineering when industrial automation is considered. Historically envisioned for electrical substations, the IEC 61850 scope has dramatically widened in the recent years. It practically represents the first telecontrol standard that includes the data semantics within the protocol. The IEC 61850 [17] introduces semantic interpretation of the message payload within the protocol itself.

In practice, this standard should be considered for DSO-aggregator communication and information exchange. For this purpose, a certain degree of interoperability with the IEC 61850 and the IEC CIM (IEC 61968/61970) [18] should be considered. Nevertheless, IEC 61850 is not directly applicable for impact estimation in the M&V framework and finds its applicability in the program settlement part.

C. SAREF

The SAREF reference ontology [19] specifies the core concepts in the smart appliances' domain, their relationships and mappings to other concepts used by different assets, standards, or models. Within the scope of smart appliances at building and household level, the SAREF ontology has reached the highest level of maturity.

SAREF is based on the following principles:

- reuse and alignment of (existing) concepts and relationships that are defined in existing assets,
- modularity to allow separation and recombination of different parts of the ontology depending on specific needs,
- extensibility to allow further growth of the ontology, and
- maintainability to facilitate the process of identifying and correcting defects, accommodate new requirements, and cope with changes in (parts of) SAREF.

The SAREF requires one set of mappings to each asset, instead of a dedicated set of mappings for each pair of assets. Even if different assets share some recurring, core concepts, they often use different terminologies and adopt different data models to represent these concepts. When using SAREF, different assets can keep using their own terminology and data models, but still can relate to each other through their common semantics.

The main concepts of SAREF are listed in alphabetical order:

- *Building Object (Door, Window)*

- *Building Space*
- *Command (e.g. OnCommand, OffCommand, PauseCommand, GetCommand, NotifyCommand, SetLEvelCommand)*
- *Commodity (e.g. Electricity, Gas, Water)*
- *Device (e.g. Switch, Meter, Sensor, Washing Machine)*
- *Device Category*
- *Duration Description*
- *Function (Actuating Function, EventFunction, Metering Function, Sensing Function)*
- *Function Category*
- *Profile*
- *Property (Energy, Humidity, Light, Motion, Occupancy, Power, Pressure, Price, Smoke, Temperature, Time)*
- *Service*
- *State*
- *Task (e.g. Cleaning, Safety, Entertainment)*
- *Temporal Entity*
- *UnitOfMeasure (e.g. Currency, EnergyUnit, Power Unit, Temperature Unit).*

The listed concepts are applicable for DR M&V purposes, as they provide a qualitative description and insights about relationship of smart home appliances. This part is a prerequisite to perform an impact analysis of a DR program.

The SAREF4BLDG [20] is a dedicated extension of SAREF ontology for buildings designed by buildingSMART International and published as the ISO 16739 standard. The idea behind this SAREF extension is to facilitate the interoperability between architects, engineers, consultants, contractors, product component manufacturers, and applications managing building information involved in the different phases of the building life cycle. In SAREF4BLDG there are classes and subclasses for geospatial data dedicated to buildings and the relationship between spaces. Additionally, there is a class representing building devices. This SAREF extension could be useful for M&V of DR, however when making an impact assessment from the aggregator perspective, such data could be useful for making proper classification of buildings involved in a flexibility program.

IV. Results and Key Findings

After the performed analysis, it can be deducted that none of the existing data models related to the scope of flexibility activation in residential buildings and beyond, covers the full semantic scope necessary to perform M&V impact estimation of flexibility programs entirely.

The key quantities [8] obtained from a DR M&V are:

- *calculated baseline load* (product of estimation)
- *calculated reduction* (difference between the calculated baseline load and observed load)
- *financial settlement amounts* (payments or penalties based on the calculated reduction)

Besides the calculated load, none of the mentioned quantities can be directly measured when direct load control is applied. To minimize the errors, both estimates, and communication technologies should be properly selected and applied. Information provided from OpenADR can be used for immediate verification of load reduction, though additional information for a specific load curtailment event should be provided. In this context, SAREF ontology could provide useful insights about relationships and assets involved in a demand response program in order to gain more variables for impact assessment.

A common information model covering the entire semantic scope and value chain in the flexibility does not exist. There is no general semantic model equivalent to IEC CIM in the electric grids. In recent years, there have been several attempts to develop ontologies which are built to cover such purpose. An example is the Brick Ontology [21] which consists of an extensible dictionary of terms and concepts in and around buildings, a set of relationships for linking and composing concepts together, and a flexible data model permitting integration of Brick with existing tools and databases. The Brick ontology is a hierarchical class model. The postulate is that in the process of identifying an appropriate class for an entity, a user can browse the hierarchy from the most general classes (equipment, location, sensor, setpoint, substance) to the specific class whose definition best describes the entity [22].

Furthermore, a similar approach is undertaken by the Project Haystack where the data description task employs a data tagging approach. The tags are designed as semantic carriers. Markup language is self-describing describing the data. This is important for data model extensibility, as typical ontologies utilize strict ontological relations, and the user needs to comply with the selection of abstractions within the standard. In such tagging-based model standardized descriptive vocabulary and a transport mechanism are defined, while not imposing a full strict ontological hierarchical model. The semantic information is encoded in the form of properties or tags.

A tagging-based model used for M&V of DR could be risky in the sense that the absence of a clear class hierarchy could lead to misnaming or wrong tags.

The inexistence of a rules for a clear composition of tags and their selection could be an issue, especially when performing impact assessment of a DR program based on load curtailment. The interrelation between assets and concepts on a building level is of meaningful importance.

V. Conclusion

Proper monitoring and verification of a demand response program based on load curtailment requires proper program settlement and impact estimation. For program settlement purposes existing standards, such as OpenADR and IEC 61850 are applicable as part of the functional architecture for flexibility activation and communication between a DSO, aggregator and the flexibility provider.

When considering impact estimation of a flexibility program based on load reductions, additional semantic information for involved assets is needed. This is crucial for obtaining a relevant ex-post analysis of such programs. Existing data models (i.e. SAREF) offer such solutions, but a certain semantic interoperability between communication standards and a ontological data models should be developed.

Interoperability must work both at technical and at semantic level. For assuring proper M&V ex-post analysis and program impact assessment, consistent and non-ambiguous data interpretation is an absolute must.

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