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System Integration and Data Models to Support Smart Grids Energy Trading

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Abstract: As smart grids gained relevance in the renewable energy landscape, the demand for new data management models became evident. Independently, whether emerging models are centralised on the Transmission System Operators (TSO), Distribution System Operators (DSO), or even on a third-party entity/aggregator (under proper regulatory supervision), the complexity of integration and interoperability of heterogeneous systems are worsened by the increase of renewable energy sources - given its potential reach and the diversity of solution providers. This work provides a detailed study of the main systems concerns present on TSO and DSO platforms alike, and main concerns in relation to renewable energy sources, sensor devices (e.g., smart meters and Internet of Things (IoT) devices) and processes. Furthermore, this work also carries out an analysis of the available integration studies - including a study case. Finally, this work proposes a top-level ontology-based standardisation for smart grid integration to support energy trading initiatives.

Keywords: *smart grid, sustainable energy, renewable energy, energy trading, energy informatics*

1. INTRODUCTION

Apart the current COVID-19 pandemic, climate change has been the top agenda item for governments globally for the last decade. Increased CO2 emissions, dependence on fossil fuels and their impact on the environment, have seen the rise in demand for renewable and more sustainable options, primarily driven by public opinion. Most electricity grids in the world have needed to adapt in order improve grid stability, reliability and resilience and meet growing electricity demand.

In 2007, European Union (EU) leaders [1] agreed a set of targets which they aimed to meet by 2020. When these targets were brought into legislation, they were considered highly ambitious, they included a 20% cut in greenhouse gas emissions (from 1990 levels), a 20% of EU energy from renewables and a 20% improvement in energy efficiency. More recently, an even more ambitious targets at least 32% renewables by 2030 is bound at EU level [2]. The term Smart Grid (SG) came to prominence in 2007, when it was defined in the Energy Independence and Security Act (EISA) of 2007 [3]. The intention was to clearly provide guidance for the evolution of the grid, from digital information and removing of barriers.

SG have had to transform quickly, technology adoption has significantly increased over the last decade, enormous integration of renewable energy options, such as wind and solar have put serious strain on the grid operators and introduced a great deal of issues [4], [5]. For some grid operators this is proving to be a real challenge [6]. A topology that was already complex to monitor and react accordingly has become even more

convoluted [7]. The traditional power plants, the distribution systems (for industrial plants, building offices, community houses and more) and all the monitoring subsystem (e.g., PMUs and electronic relays) have been overloaded with the new complexities brought by SGs [8].
All sorts of renewable energy sources added to the grid (e.g., Photovoltaic (PV)/solar, wind, biomass) and demands of Household Energy Storage (HES) and/or Community Energy Storage (CES), create a scenario where the problems of integration - both the energy itself and the information necessary to support such complex new scenarios - are more urgent and demand new approaches and solutions.
The rest of this paper is organised as follows. Section 2 surveys some related work covering the main topics explored in this paper. Section 3 describes the TSO/DSO landscape concerning data integration. Section 4 explores the challenges and opportunities of the SGs. Section 5 presents a high-level ontology-based standardisation proposal. Section 6 concludes the paper and suggests future work. Finally, a list of the abbreviations and acronyms used in this paper can be found as an appendix at the end of the paper.

2. RELATED WORKS

In the next subsections, we explore a few the state-of-the-art publications on SGs and the complexities involving their integration on the traditional energy grid. Also, we explore references of ontology in the energy sector that supported our ontology-based standardisation proposal.

Integration concerns

The work of [9] approaches the Smart Grid (SG) integration as an evolution of power networks due to the ubiquitous presence of new sensors or IoT in general – with all the heterogeneous protocols and sensor devices that integrate them. What once was considered as isolated systems, now must be integrated to deliver new energy management resources. The authors propose a “Web of Energy” with guidelines to tackle performance, accessibility, and availability. The Actor Model paradigm presented in the paper brings insightful considerations on modelling of the systems involved. However, as a proposal of an overall development model it can face limitations as the subsystem are becoming increasingly specific.
In the work [10], the authors highlight the importance of energy management to reduce the overall expenditure on electricity and the need of flexible systems to encompass a broad range of consumers, IoT, data storage and analytics. They proposed a hardware implementation capable of gathering the necessary info and algorithms to develop cost optimisation. However, the ”local” operation of such devices can be tricky and face problems related to users’ interaction, they have also implemented a web solution associated with the IoT implementation where it is possible for the user to check its consumption behaviour. Although the implementation covers a broad range of important points related to energy consumption, its scope falls short of a more generic approach to integrate diverse IoT devices.
The Data and Citizen-centric Approach (DCA) discussed in the work of [11], introduces a model to support SG and, in a broader aspect, Smart City (SC) governance. In this model, the biggest challenges are customer engagement, legal framework and technology and system integration – especially in what concerns sensing, e.g., Radio-frequency Identification (RFID), actuators, smart meters (new and legacy) combined with sensitive citizen data, and standardisation in the smart power sector. Several approaches are discussed, such as a “mediator” software that could translate the data to keep uniformity amongst systems, or a Service-oriented Architecture (SOA) implementation with data integration functionalities. However, the standardisation concerning data integration is still the best long-term alternative.

Ontology in energy

Ontology is a branch of philosophy that studies the kind of structures of objects, their properties, events, processes where they interact and their relation in all areas of reality [12], [13]. However, the use of ontology is flexible, and the levels of detailing vary significantly depending on its usage.
The ontologies can be interpreted in levels, a proposed by [14] when lists three levels of ontologies in energy: upper ontology (referenced by other ontologies), domain ontology (defining concepts using classes, entities and relationships) and application ontology (which extends domain ontologies for applications). In [15], there is also references to ontologies for SG divided in layers, such as: field layer, knowledge layer and management layer.
In a less generic approach, the Common Information Model (CIM) describes a well-established International Electrotechnical Commission (IEC) standard 61970/61968/62325 [16] expressed in Unified Modelling Language (UML) notation. CIM can address the complexity of data but has obstacles within its standards. As the standard has developed confusions – not in compatibility between versions, but as the standard is in the English language – non-English-speaking vendors must develop translations for their users of the system

[17]. Also, as in general systems do not have a native use of UML format for data, real system then ultimately has to convert the data structure to support the data management [17]. As a result, ontologies offer a better data integration with interoperability [18] and offers a powerful tool in direction to a standardised model.

3. TSO AND DSO SYSTEMS LANDSCAPE

TSOs and DSOs have always shared common challenges on what concerns the integration of their distribution system and the recurring need to renewal ageing grids. More recently, the overgrowing need for data and new demands for flexible services require coordinated efforts and constant investments [19] in communication hardware and software - especially when faced with the integration of large number of renewable energy sources. One of the main priorities is to achieve such a level of integration that would connect dispersedly distributed resources and/or new service providers into the market and the electricity system as a whole and, at the same time, ensure security and value for customers [20].

The importance of cooperation in the energy sector [2], [4] (transmission, distribution, micro-generation and so on) in all administrative levels is mandatory in face of the challenges of combining distributed flexible resources into an innovative environment. Examples of that are initiatives such as [21] where TSOs and DSOs create a cooperation for the creation of efficient network codes, the Network Code Implementation and Monitoring Group (NCIMG) bringing together experts from both TSO and DSO in 2018.

With the increasing number of Distributed Energy Resource (DER) on the grids, DSOs will need to have a more effective role while guaranteeing the integrity its network and, at the same time, fomenting DER services – and a satisfactory coordination between TSOs, DSOs and DERs will be compulsory [22].

In areas where a decentralised data exchange is the current model – most common model around the world and especially in Europe – it is noticeable a trend to involve TSOs, DSOs and all sorts of third-party participants. These Data Exchange Platforms (DEPs) motivations are efficiency in data management, flexibilization for new market entrants and, most importantly, empowerment of customers. A few implementations of such collaboration are already in course.

For example, the Datahub is a central IT platform jointly developed by Eandis [23], Elia [24], Infrax [23], Ores [25], Resa [26] and Sibelga [27]. It aggregates the data necessary to evaluate the flexibility services used (e.g., the users' consumption profile) and estimates the amount of energy generate (or simply not consumed) in a given period of time. This way, the Datahub has the fundamental information to guarantee an uneventful operation in the controlled flexibility market.

The growing share of DER in the distribution grid offer possibilities for both the TSO and the DSO to use resources for the mutual benefit [28]. These integration initiatives foment innovation, such as The International Renewable Energy Agency (IRENA) reports in [29] identifying 30 innovative solutions to enabling technologies, new market and business models, and operation. From that, as suggested by [30] in Table 1, the innovation landscape for renewable energies expanded significantly.

4. SMART GRID LANDSCAPE

SGs can principally be defined as the use of technology across the energy grid, but differing research centres and agencies have differing ideas on what a smart grid can offer, and thus how it can be defined.

The United States (US) research agency, Electric Power Research Institute (EPRI), has worldwide hubs specialising research in smart grids and utilities, resulting in contribution to the definition of standards as set by the Institute for Electrical and Electronic Engineers (IEEE) [31]. The EPRI states that it's concept of a smart grid is that the use of information and communications technology through the generation of electricity can help minimise environmental impacts, improve reliability, enhance markets, and aid customers with reduced costs and improved efficiency.

The ABB Asea Brown Boveri (ABB) is a global technology company that is focusing on a more productive and sustainable future [32], and defines a smart grid as a bidirectional flow of power and digital information, by modernisation of the utility infrastructure, through improved efficiency, enabling new applications, lowered costs, conservation of power, and improved quality to the customer [33]. In July 2009 a smart grid assessment released by the US Department of Energy (DOE) described a smart grid as not a 'thing' but could be described as a vision, with a role as a transactive agent, and that would enable financial, informational, and electrical transactions among consumers, grid assets, and other authorized users [34], [35].

This assessment was characterised by performance goals, including to involve customers participation, and provide better services, and to make the grid more resilient to disturbances, such as natural disasters [36], as well as concepts for operation efficiency and the enablement of new products and services [34], [20].

Table 1. Enabling solutions for flexibility in the power system [32]

○ **Enabling technologies**		○ **Business Models**		○ **Market Design**		○ **System Operation**	
1	Utility-scale batteries	12	Aggregators	17	Increasing time granularity in electricity markets	25	Future role of distribution system operators
2	Behind-the-meter batteries	13	Peer-to-peer electricity trading	18	Increasing space granularity in electricity markets	26	Co-operation between transmission and distribution system operators
3	Electric-vehicle smart charging	14	Energy-as-a-service	19	Innovative ancillary services	27	Advance forecasting of variable renewable power generation
4	Renewable power-to-heat	15	Community-ownership models	20	Re-designing capacity markets	28	Innovative operation of pumped hydropower storage
5	Renewable power-to-hydrogen	16	Pay-as-you-go models	21	Regional markets	29	Virtual power lines
6	Internet of things			22	Time-of-use tariffs	30	Dynamic line rating
7	Artificial intelligence			23	Market integration of distributed energy resources		
8	Blockchain			24	Net billing schemes		
9	Renewable mini-grids						
10	Supergrids						
11	Flexibility in conventional power plants						

The EU states that a smart grid is defined in the Trans-European Networks for Energy (TEN-E) regulation as one of the twelve trans-European energy infrastructure priority corridors and areas. It explains that an electricity network should integrate, in a cost-efficient manner, to ensure a power system, with high level or quality and low losses, with generators and consumers that can also generate (prosumers) [37].
The European Commission (EC) in 2006 published a booklet defining a SG as not a technical venture, but that it would address commercial and regularity issues as well [38]. To achieve that, SG should provide solutions to allow power injections from distinct energy resources (rapidly and cost effectively), be based open technical standards and protocols, facilitate cross border trading (through regulatory and/or commercial agreements), develop Information and Communication Technology (ICT) to enable efficiency and support backward compatibility and interoperability amongst old and new equipment in the grid.
Finally, the United Kingdom (UK) Department of Energy & Climate Change (DECC) defines the SG as an electricity network capable of integrating all participants (e.g., generators, consumers and prosumers) to efficiently deliver sustainable, economic and secure electricity supplies [39]. It also highlights the importance of developing innovative services and products to improve monitoring, control, and communication.

5. HIGH-LEVEL ONTOLOGY-BASED STANDARDISATION

As distinct as the very definition of a SG can become around the globe [18] (concerning diverse technologies, regulations, standardisation efforts and so on), the underlying concept of efficiency achieved through the establishment of bi-directional communication is a constant [4] to achieve interoperability. All devices participating in a SG would need a common structure of data communication that would allow users and systems to share information across the energy network. To achieve that, an Ontology (a method for sharing knowledge through a formal representation of real-world domains) is a powerful tool [18]. As such, and for the scope of this project, our Ontology offers a framework for typology of distinct SG system components, defines the key concepts connection these systems and suggests a neutral language to integrate its components [40].
The ontology described in Figure 1 is part of the Cooperative ENergy Trading System (CENTS) project. This project is a project coordinated by the International Energy Research Centre (IERC) and will rely on the industry experience from mSemicon [41] and Community Power [42], and the research capabilities of University College Cork (UCC) [43], National University of Ireland Galway (NUIG) [44], and Dublin Institute of Technology (DIT) [45]. CENTS is a disruptive technology platform for the electricity sector where consumers, producers, prosumers (simultaneously production and consumption) and communities will be empowered with the infrastructure to generate their own electricity, earn from the electricity generation, and finally, to be an integral part of decarbonising their homes and communities for sustainable living.
This ontology helped to define how the sensors and IoT devices – energy storage (battery status), PV readings, temperature, transactions (blockchain-based), and any other meters and sensors in general – would be integrated to the CENTS platform and be the base for the energy trading and user empowerment.
In this use case, the class Hub represents a local hardware device responsible for collecting all relevant data and transmitting it a central platform and integrating also the trading data structure.

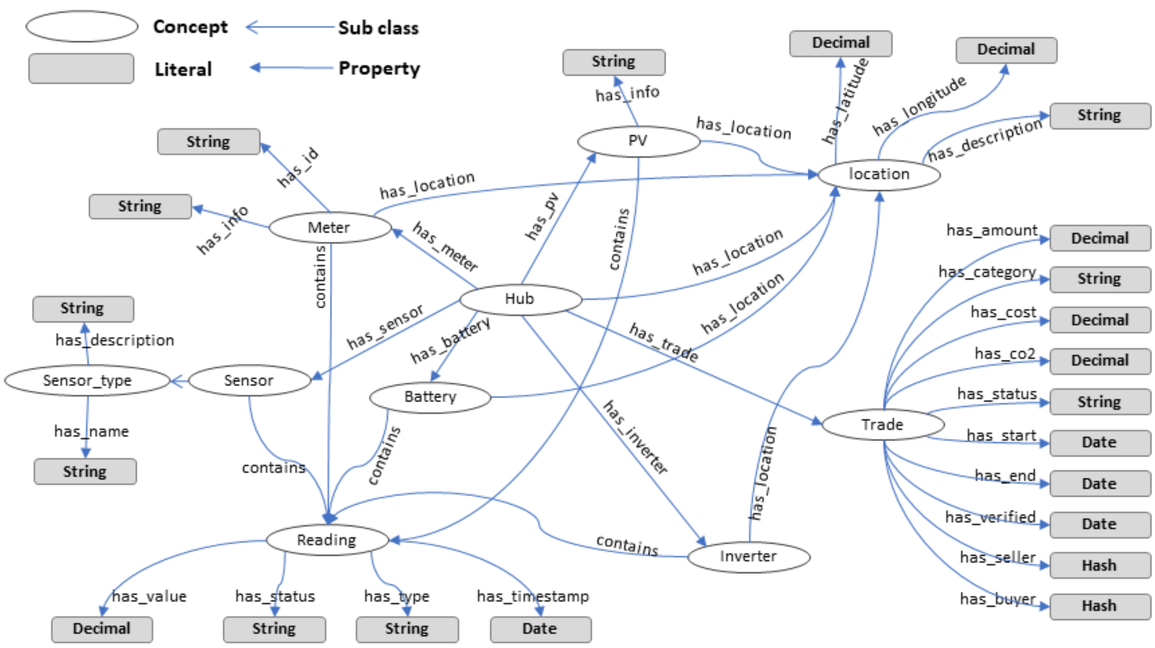

Figure 1. High-level smart grid ontology.

6. CONCLUSIONS

The high-level ontology described in this work is intended to pave the way for the standardisation of data integration in what concerns Smart Grid integration. A formal way to describe the information to be shared between the systems and subsystem present on a TSO/DSO and Smart Grid will facilitate commercialisation, operation and control of energy trading and empowering the customer.

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