Service Orientation and the Smart Grid state and trends

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ORIGINAL RESEARCH PAPER

Service Orientation and the Smart Grid state and trends

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Abstract The energy market is undergoing major changes, the most notable of which is the transition from a hierarchical closed system toward a more open one highly based on a "smart" information-rich infrastructure. This transition calls for new information and communication technologies infrastructures and standards to support it. In this paper, we review the current state of affairs and the actual technologies with respect to such transition. Additionally, we highlight the contact points between the needs of the future grid and the advantages brought by service-oriented architectures.

Keywords Smart Grid · Electricity distribution · Service-oriented architectures · Web services

1 Introduction

Service-oriented architectures (SOAs) are a modern way to build large-scale interoperable dynamic systems, which have shown their effectiveness in addressing the integration problem for enterprisers and even enabling the creation of virtual enterprisers, for example, [34], while energy infrastructures have evolved into large geographically pervasive complex system forming the backbone of any country. Lately, the evolution is gaining momentum and there are significant signs of a paradigm shift. The communication between components in the electrical domain is getting bidirectional replacing the old model of reading data and using it centrally. Supervisory control and data acquisition (SCADA) systems are getting "smarter," and more information is available about grid's operation. In addition, the old mechanism of estimate and bill customer consumption is declining while making space for the advanced metering infrastructure concept.

The change underway is driven, on the one hand, by technological innovation with, for example, the introduction of renewable-based generation facilities (both at a large- and micro-scale level) [20] and distributed power sources [32], on the other hand, by the political push to break the monopolies and unbundle the market (e.g., [10,25]). Recently, another trend is receiving growing attention, that is, the concepts falling under the name of the Smart Grid. The challenges of the Smart Grid are addressed by various EU directives, which emphasize its strategic importance [15–18], while other governments, like the US one, promote active research in the field with major research programs: cf. the US 4 billions dollars in Smart Grid technologies and electric transmission infrastructure.[1] In the framework of the Smart Grid, an essential element is information that the actors of this new approach to the electricity grid need to exchange with each other to successfully enable the new Grid functionalities.

In this paper, we study the current situation of the power grid from an information exchange perspective with particular attention to service orientation. We see what are the current contact points between the actual grid and the Smart Grid approach including overviewing existing standards and underway standardization processes. We focus in our survey

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[1] http://www.energy.gov/news/7503.htm.

on the aspects related to the information exchange between the players of this new energy paradigm, what type of information is exchanged and we provide how gaps in information exchange can be overcome with a service-oriented approach. We also provide a discussion of the trends toward the Smart Grid and how SOAs will play an even more important role in supporting that vision.

The paper is based on our preliminary work on the energy markets and service technologies [41], our experience in agent-based interactions with Smart Meter for energy trading [6] and the study of the current distribution layer of the Power Grid [42]. The paper is organized as follows, Sect. 2 introduces and gives a general overview of the energy sector. Section 3 introduces the concept of Smart Grid. The role of service-oriented architecture (SOA) in the paradigm of the new Grid with the challenges arising are described in Sect. 4. Existing and forthcoming standards are presented in Sect. 5. Section 6 describes the related work on energy and information exchange. Section 7 concludes the paper.

2 The electricity sector

The electricity sector forms the critical infrastructure of any nation. It must be reliable, highly available, and pervasive. Let us look at how it is currently organized. In the past, and in some countries still, the electricity sector was dominated by one player that had a highly vertically integrated business with all the operations from power generation to electricity distribution, to customer management under a single big institution. The current trend is for the unbundling of the sector: the various operations of the energy company are split into several independent companies that deal specifically with one function of the electricity business. Of course, in this situation, the communication and information exchange between the companies become extremely important.

Figure 1 provides a simplified schema of the power grid. One notices an organization in transmission (extra high and high voltage) and distribution grid (medium/low voltage). Energy is mainly produced in large power plant facilities at the High Voltage level by few authorized actors, while end users exist mostly at the medium and low voltage. The structure is highly hierarchical. The new directives which promote the unbundling of the electricity sector aim at placing more actors at the higher levels of this figure to improve efficiency, reduce costs, while keeping the same level of service and reliability.

The energy sector does not only include the physical infrastructure where energy is produced and distributed, but it also includes the data exchanges that have to take place in order to manage energy billing and trading, and, in addition, the business involved in the creation of added value around delivering of energy, cf. Fig. 2.

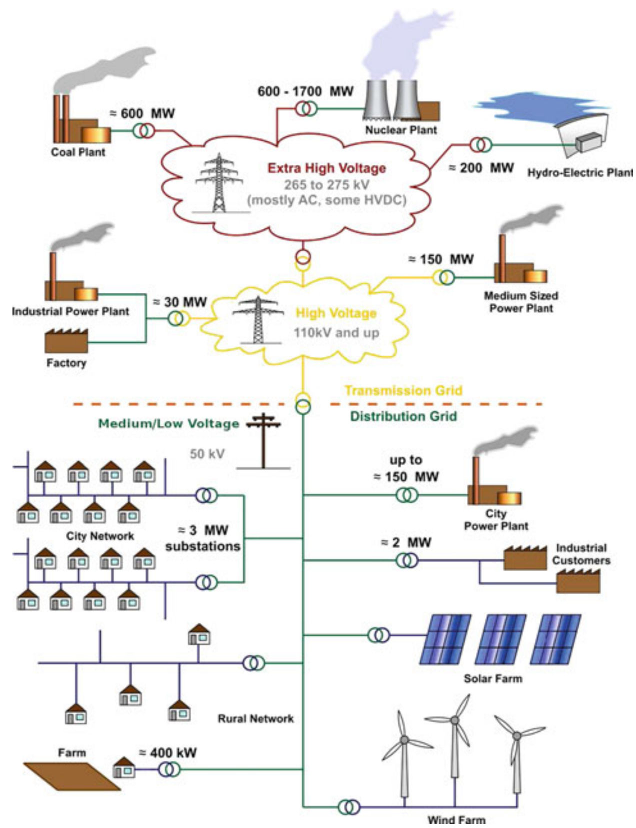

Fig. 1 The physical organization of the power grid (*Source* adapted from Wikipedia)

- **The physical layer** is the lowest in the stack and it interacts directly with the electrical apparatus (e.g., transformers, switchgear, relays) that belong to a distribution substation and power plant control equipment. The physical layer deals directly with the energy that is produced and transferred to the end-user. The fundamental element of the physical layer is the Power Grid that enables bringing the energy from the source (i.e., power generator) to the sink (i.e., end-user).
- **The data layer** spans from the control data used to supervise and actuate the physical equipment, to all the interactions necessary to properly govern the different systems involved in production, transmission and distribution of energy. To enable remote operations on the physical equipment and interactions between the various components of the Grid (e.g., sensors and actuators) and also to ease the management between different substations, International Electrotechnical Commission (IEC) has defined some standard intercommunication protocols (i.e., IEC-61850, IEC-61968, IEC-61970, these standards are illustrated in more detail in Sect. 5). In order to get the benefit from this data, the resulting information has to be shared not only inside the company, but with all the stakeholders that need it, thus creating

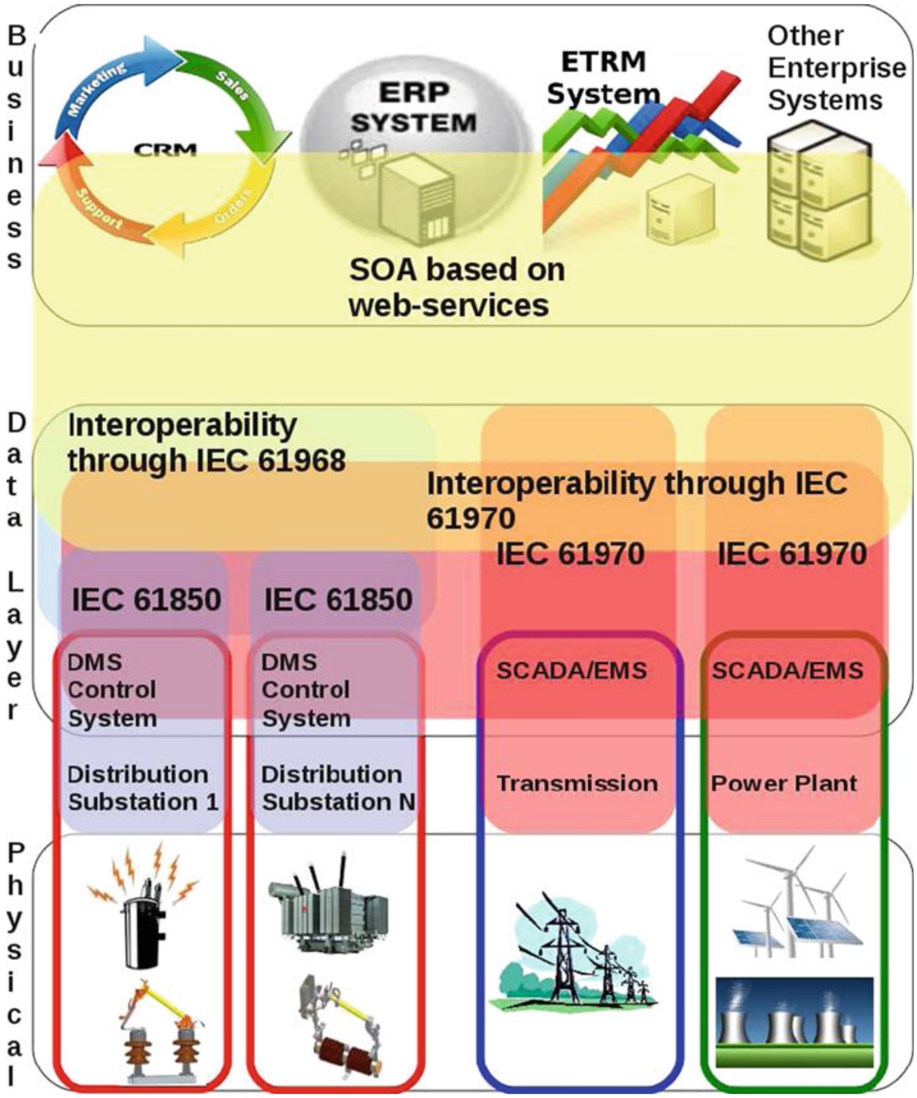

Fig. 2 Information exchange across layers

a flow of information inside and outside the company; to achieve this objective, standardization techniques in a multi-player environment are required.

– **The Business layer** is formed by information, opportunely aggregated or transformed, coming from the data layer. Therefore, it is a key element for running the business of electricity. It can be used to measure company performances through key performance indicators, to create new business models to make important forecasts for future energy trading opportunities and needs. This information is critical to allow the proper operation lifecycle of the company and is frequently managed through Enterprise Resource Planning (ERP) systems. In addition, for risk management and market monitoring purposes, Energy Trading and Risk Management (ETRM) systems are essential. Moreover, data coming from the metering operations are necessary to provide billing services to customers, these data are often used to populate Customer Relationship Management (CRM) systems.

2.1 Stakeholders and flows

In the energy sector, one can recognize the following main functions: power generation, grid management, energy supply, metering, and billing. In the past, all these functions were bundled into one monopolistic company usually state owned. Today, the functions are separate and, in the most advanced case, there is competition among more companies providing the same functionality.

Inside such vertical markets, there are three major flows: an energy, data, and financial flows. The peculiarity of the *energy flow* is that there must always be a balance between energy supply and demand on the network. This entails the need for a complex control systems that, based on physical properties of the grid and distributed sensors, guide energy producers and grid operators to keep the whole systems in balance (e.g., by having a power generation facility kicking in whenever the frequency characterizing the power network goes below a certain value). This is based on special-purpose systems, known as supervisory control and data acquisition and energy management system (EMS), that interface directly with sensors and controllers of the power plants and power grid.

The *data flow* involves various actors: metering and billing (suppliers and end users), provisioning based on demand and forecast (supplier), routing the appropriate energy along the correct paths and control energy production according to forecast and need (producer and grid operator).

The *financial flow* consists of the money flows that all the actors described above move thanks to the added value provided to the end user. This economic side is closely connected to the information flow since it is based on the information the actors collect (e.g., metering and energy orders received on the market), while is very poorly related to the actual energy flow, that is, one does not necessarily pay for the electron that he is consuming, but simply for an electron that is produced somewhere to balance his need.

2.2 Short-, medium-, and long-term markets

A key characteristic of the power grid is the inefficiency in, and also economic disadvantage of, storing energy at any reasonably large scale. This, with the additional requirement of having an always in-balance grid, calls the need for real-time control of the grid and trustworthy provisioning. Forecasting at different time granularities becomes then crucial to drive a constant energy negotiation. Energy negotiation is dynamic and with different timescales at the wholesale level [12] (on the other hand, end users make contracts with fixed usage upper bounds) and calls for having the following types of markets.

– *Long-term market:* producers and suppliers hedge their energy needs for the long term (e.g., buy or sell energy in long term future contracts). These contracts may be physical or purely financial. The time-frame granularity is the day.
– *A day-by-day market (known as day-ahead market):* producers and suppliers adapt their consumption to operational needs (e.g., maintenance, shifts and predictable fluctuations of workload/consumption), by buying/selling energy on a day to day basis. This can be done in a spot market, through brokers or without middlemen with bilateral agreements. The market closes before the production and consumption take place, usually 24 h in advance. At that time, all buyers and sellers must report to the Grid operator the quantities they have bought or sold. The time-frame granularity is the hour.
– *A real-time market:* producers and suppliers trade energy to balance their real consumption, since estimations done days before might be incorrect or because of unexpected circumstances. If a transaction helps to balance the Grid, the price of the energy at wholesale level can go even tenfold over the normal market price (balancing bonus), on the other hand if it brings more imbalance, a negative price can be applied and be very high (balancing fine). The time-frame granularity are the minutes.

3 The Smart Grid

The Smart Grid is an overloaded term used to indicate the evolution the Power Grid is undergoing. According to Wikipedia,[2] the Smart Grid is such when two-way digital communication is in place and consumer's appliances can cooperate with the Grid. For the National Institute of Standards and Technology (NIST),[3] it "delivers electricity efficiently, reliably, and securely," thanks to "a two-way, digital, interoperable national network." Many more definitions exist and prove that the Smart Grid is not one single shared concept but rather, as discussed in the report issued by the Department of Engineering and Public Policy of Carnegie Mellon University [36], a set of views depending on the actor involved in the grid. In particular, the benefits for each actor include:

– The *customer* can benefit from real-time tariffs that really reflect the price of electricity, react with his loads based on the tariffs and receive information directly from the meter about his consumption and costs.
– The *distribution companies* can have a higher level of automation to manage critical situations and a more selective way of shedding load (e.g., based on the importance of the service provided: hospitals or police stations might be the last to be removed from the network due to their social and safety importance). For distribution companies Smart Grid also enables scenarios to manage easier integration (or enable islanding of subsets of the Grid during emergencies) of more distributed energy generation facilities in the low level Grid.
– The *generating and transmission companies* can benefit from a more "computerized" Grid with more information and data about critical Grid measures (e.g., network's voltage phase). Having more information enables more automatic and distributed decision-making even far from the control center, thus optimizing the Grid operations.

2 http://en.wikipedia.org/wiki/Smart_Grid.

3 http://www.nist.gov/smartGrid/faq.cfm.

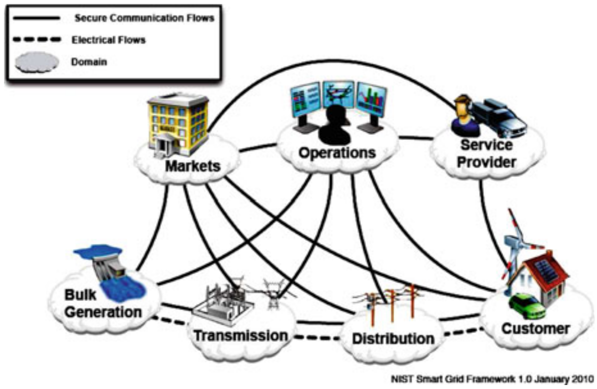

Fig. 3 Smart Grid framework (*Source* NIST)

The many actors and their domains involved in the Smart Grid landscape are presented in Fig. 3 according to the view of NIST [40]. The main elements that appear in the figure are the presence of several actors (in accordance with the unbundling tendencies of the sector) and many communications flows, while the electrical flow follows mainly a top–down stream from the power plants to the end user. In particular, the role of each actor can be synthesized as:

- **Bulk generation**: Bulk generation represents the energy generation companies that have to control and actuate the power plants (therefore the interaction with the operations actor). Naturally the amount of energy generated has to satisfy the contracts agreed on the market; therefore the information exchange with the market actor.
- **Transmission**: Transmission represents the actor that has to provide the energy generated from the power plants to the whole Power Grid. The amount of energy transferred between certain points has then to be accounted on the market to complete the clearing of eventual unbalanced positions (e.g., due to incorrect forecast and energy purchase by market participants).
- **Distribution**: Distribution is the last part of the electricity Grid that provides energy to the end customer. The interaction with the customer is more rich in the Smart Grid framework than the traditional energy business since an energy and information flow might be received by the distributed generation facilities at customer level.
- **Customer**: The customer represents the new end-user of the Smart Grid. He has enhanced capabilities than the traditional "passive" energy customer. His interaction with the electricity Grid at distribution level is in fact bidirectional (i.e., he can also give his own-produced electricity to the Grid). A key element at customer level is the presence of intelligent home equipment (i.e., smart appliances) that need to interact with energy operation services in order to guarantee proper work of Demand-Response functionalities (i.e., tariff changes based on the Grid balance conditions) of the Smart Grid.
- **Service Provider**: This is one of the roles of a traditional energy company or it can be a new business opportunity provided by the Smart Grid. It essentially consists of traditional aspects such as maintenance, billing and customer service interactions with the end-user. At the same time new opportunities for home/building energy management and optimization arise.
- **Operations**: This is the most critical role of the electrical system since it guarantees its proper functioning: balance between demand and supply and quality of the delivered electricity. It is a role already key and essential in the traditional electricity system providing control and actuation on the various elements of the power system. Therefore it is not surprising that this function is connected with every other actor and sub-domain.
- **Markets**: Markets represent the actor that organizes and manages the energy exchange at financial level. The market has to be aware of detailed information about the quantities of energy actually flowed from certain producing companies, transmission and distribution (therefore the connection with all these actors and operations too) lines. It also registers offers and bids from the energy provider companies. In the future the end-user too, or a cooperative of users, might be able to interact with the market and directly buy/sell energy at this level.

An extended version of the NIST framework is shown in Fig. 4 where the interactions between the different networked subsystems are represented. The intricate picture gives, first of all, an impression of the many different networks, systems, and complexity of the information exchange.

The element that appears in virtually all definitions of Smart Grid is having, in parallel with the energy flow, an information flow that enables advanced functionalities both for the Grid operators and for the end users. A synthesis can be obtained from the U.S. Department of Energy ([38,39]) that provides the following requirements for the grid that can be achieved with the appropriate information exchange:

- to diagnose itself and take appropriate action in case of faults,
- to become more resistant to willing and unwilling attacks,
- to satisfy the users with an improved power quality meeting their needs and expectations,
- to be ready to integrate different source of power generation, and
- to give the end-users the possibility to interact and respond to electricity price signals in a distributed energy market.

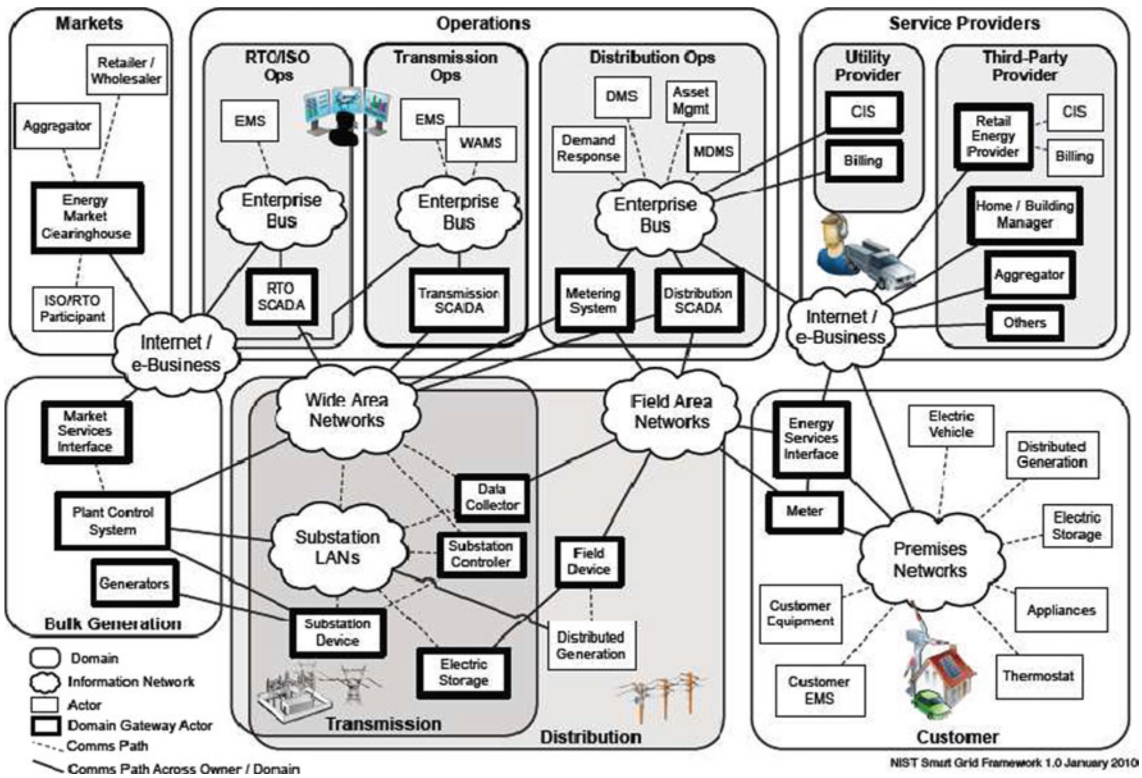

Fig. 4 NIST conceptual reference diagram for Smart Grid information networks (*Source* NIST)

4 Open grids via SOAs

The vision of the future Smart Grid, however defined, will bring unbundling of energy markets, appearance of renewable generating facilities at all scale levels, the standardization of the control elements of the power grid, the diffusion of digital/data prone Smart Meters, and especially two-way communication among end users and the grid. This will be a reality only if there are infrastructures that can support it.

4.1 Smart Grid challenges

A number of challenges need to be addressed for building such a grid. We identify the following ones as the key issues to be solved at the software level.

- **Interoperation.** The number of actors populating the energy market is constantly increasing and their capabilities as well. There is a strong need to have standards for interoperation at all levels (not only the control layer of the Grid). Furthermore, standards tend to cover the syntactic part of the interoperation, while the semantics of the message exchange is scarcely addressed.
- **Scalability.** The increase of actors also involves scalability issues. If millions of micro energy producers start trading micro-quantities of energy, there must be an appropriate infrastructure to manage this, possibly real-time, information exchange.
- **Discovery.** If the actors increase and more entities can take on the same role, one may think of discovering services on the fly. The idea of signing an yearly contract for a home, may be too limiting and one may want to switch energy supplier on a much shorter time frame. Furthermore, if anybody can be a supplier, then one may want to find a provider in the moment the energy is needed.
- **Mobility.** In the future, Grid energy consumers, and also producers, may be mobile on the Grid. Cars will be electric, but may also have energy producing and storing facilities (e.g., a solar cell roof, fuel cells powered engine). The mobile elements need to interact with the Power Grid in a transparent way.
- **Resilience to failure and trust.** The electrical power Grid is a critical infrastructure. A key performance indicator of the current energy distributors is the down time that should not exceed the few hours per year. When moving to an open Smart Grid the delivery of energy must not decrease in quality. This requires having a trust mechanism among the various players. It may also require having reliable forecasting of generation and use.
- **Service integration and composition.** The physical layer, the data layer and the business layer will have to interact more closely. In fact, any node which produces energy needs to interact with control/actuation part of

the Grid and get paid for the energy produced; the generation might be a part of a larger business process relying on the energy (e.g., one could drive an electric car while lodging at a motel, plug it into the Grid and use the car generated electricity to pay part of the bill [52]).

- **Topology.** The current infrastructure is highly hierarchical, not only in the physical infrastructure, but also in the information systems that manage the electricity system. Very few large energy producers and backbone owners exist, with few systems that control the plants and the transmission network highly centralized. But the new vision of the open Grid demands for a flat peer-to-peer network in which all actors are producers and consumers of energy, data and services.
- **Smart Meters.** The Smart Meter is likely to become the "energy gateway" of the house with more and more functionalities and embedded intelligence. Smart Meters might work as automatic bidder on the energy market knowing family energy usage and production patterns together with estimation methods based on past usage and environmental forecasts (e.g., future weather conditions).
- **Real-time.** Energy related operation such as control, actuation, distribution and trading have very strict time-dependent constraints to satisfy. All the players in the next generation Grid must interact following real-time commitments to provide and receive an energy service with the proper quality.

4.2 SOA supporting the Smart Grid

Interestingly, the just listed challenges have a natural counterpart in the service-oriented architectures. These have been traditionally built to address interoperability and scalability issues for the integration problem of enterprise information systems (e.g., [8,44–46]) or to support business process, especially across companies borders. Here, we take a different look and consider how SOAs are appropriate for the Smart Grid and look at the challenges just introduced through the glasses of service orientation.

- **Interoperation.** Web services are a technology to build Service-Oriented Architectures and address the problem of interoperation being standardized eXtensible Markup Language (XML) protocols to describe messages, remote operations and coordination among loosely coupled entities, e.g., [31]. These are already entering the energy sector as described in Sect. 6.1.
- **Scalability.** The basic SOA pattern: publish–find–bind allows to decouple service consumers from producers and to substitute, even at run-time, one component for another one. The communication, most often asynchronous, provides all the ingredients for a highly scalable infrastructure. Examples of which have already appeared in the area of eBusiness.
- **Discovery.** Discovery is one of the basic ingredients of a SOA. It needs to support the publish and find operations and is usually based on registries, but can also be realized with flooding models.
- **Mobility.** A SOA supports actor loosely coupling and behavior based binding, therefore the mobility of the elements is easily supported, e.g., [1].
- **Resilience to failure and trust.** Protocols exist to enable a Web service based SOA with trust, privacy and security support. This can provide the basic for a secure infrastructure. Reliability will also have to be pursued with appropriate energy technology which is beyond the SOA.
- **Service integration and composition.** Service integration and composition is the key added value of a SOA and many examples exist on methodologies to support this, e.g., [2,5,7,14,30].
- **Topology.** SOAs support any kind of topology. The hierarchical client-server one is less common, but can be realized. The P2P topology is most often the one realized.
- **Smart Meters.** In the SOA paradigm the Smart Meter is basically a service provider and a service consumer at the same time. It invokes other services to interact on the market and also provides services to other market participants interested in energy purchase. It also interacts in a service-oriented fashion with intelligent home appliances that require energy at a certain time.
- **Real-time.** Solutions are available to introduce enhancements to SOA paradigm in order to provide an appropriate quality of service and satisfy real-time constraints, e.g., [43,51].

4.3 Discussion

The Smart Grid is thus amenable to be supported by SOAs, though there are some differences with traditional SOA approaches. Table 1 shows the main points of contact and dissimilarity between the traditional SOAs and those for the energy sector. A natural common point is the use of SOA technologies for integrating heterogeneous systems, thus enabling their interoperability. Beyond this common feature, several differences lay that must be taken into account when dealing with energy systems. Traditional SOA is mainly used in the business process domain managing complex supply chain and interactions between a multiplicity of actors whose applications are usually triggered by specific events. Usually, the paradigm of these interactions is asynchronous. On the other hand, the SOA for energy applications must tackle some peculiarities of this type of business and systems. First of all, the requirements for real-time interactions between the various subsystems and components of the energy-related

Table 1 Similarities and differences between traditional SOA and energy-oriented SOA

Traditional SOA Vs. Energy SOA	
Similarities	
• System integration • Interoperation	
Differences	
• Supply Chain management	• Interaction with non-Energy systems (e.g., ERP, CRM)
• Event-based applications	• Real-time requirement
• Business process management	• High security (authentication, encryption for market trading)
• Asynchronous long-running business process and transactions	• Trust mechanism for services provided
	• Interaction with low level electrical interface standards (IEC standards for SCADA/EMS) • Fault tolerance

information and communication technology (ICT) involve SCADA and EMS systems and low level electric applications embedded systems. Being these systems highly important and mission critical, real-time constraints together with fault tolerance, security, and trust mechanisms in the service provisioning are essential requirements that a SOA for the electricity sector needs to satisfy. An interaction with non-strictly related energy systems such as CRM and ERP is also required to have a complete interoperability picture.

Another issue that is central in enabling the SOA solutions for the Smart Grid is of course an appropriate communication infrastructure. It is not the focus of the present work, but it is worth to mentioning the adaptation required by the telecommunication/telecontrol infrastructure to support the enhanced amount of information data and control signaling that the Smart Grid requires [54]. The telecommunication aspects and its infrastructure must not be taken for granted, since they found the basis to build more complex service-oriented software layers on top.

5 Standardization for Smart Grid SOA

One of the success factors of SOAs has been the availability and wide adoption of standard languages for interoperation. The XML-based set of languages and standards known as web services have been paramount for the movement of service orientation [44]. Similarly, the Smart Grid needs common standards and frameworks. To see where information flows and where standardization is mostly needed, let takes again the NIST Smart Grid vision, Fig. 4, and highlights the key points. Figure 5 considers the actors and the subnetworks highlighted by NIST's framework and shows where the different standards apply. The different actors communicate together through different networks (clouds in the figure) and each line of communication has (or should have) its set of rules to exchange information. Each symbol on top of the communication lines between the actors characterizes the standards that are used in the specific communication. From the figure, we see that the IEC standards basically monopolize the information exchange between the power systems and the information systems that control them and enable the operations for production, transmission, and distribution. These IEC standards for interaction with power equipment are considered by NIST as the "foundational standards"[4] for Smart Grid interoperability. On the other hand, the standardization is not so clear in the interactions with the market: here, there is more heterogeneity and, although the interaction happens through the Internet, there is not yet a unique way for energy producers, control center operators and traders on the market to speak a common unified worldwide language. Closer to the end user, you see a new energy-related network known as Energy Home Area Network that is inside user's premise and enables information exchange between smart appliances and energy-aware home equipment; efforts are present to define a common language for communication even at this level. At the moment, we see some empty lines of communication or some attempts for technologies that do not have a complete agreed standard. In particular, the interaction between the customer and the energy service provider for energy metering or demand–response-enabled equipment control has no clear and complete definition yet. A first effort is the Organization for the Advancement of Structured Information Standards (OASIS) Energy Market Information Exchange (eMIX), which can be applied for demand–response interactions only. The same appears in general in the interaction between the energy service provider and the operation control of the electrical system for which a generic interaction through an enterprise service bus is considered.

5.1 International Electrotechnical Commission

The International Electrotechnical Commission has realized an important standardization effort for data and control protocols for the energy generating assets, the transmission, and distribution grids. In particular, the IEC Technical Committee 57 has provided several inputs to this interoperation challenge between energy operation equipments. Here, we want to highlight the main aspects of the standards and their use and not analyze every single small detail of each one.

IEC has developed a standard called IEC-61850 that aims at obtaining a high level of automation at electrical substation level. It defines the protocols and data types for the communication between intelligent electronic devices (IED) usually

[4] http://www.nist.gov/smartgrid/grid_20101013.cfm.

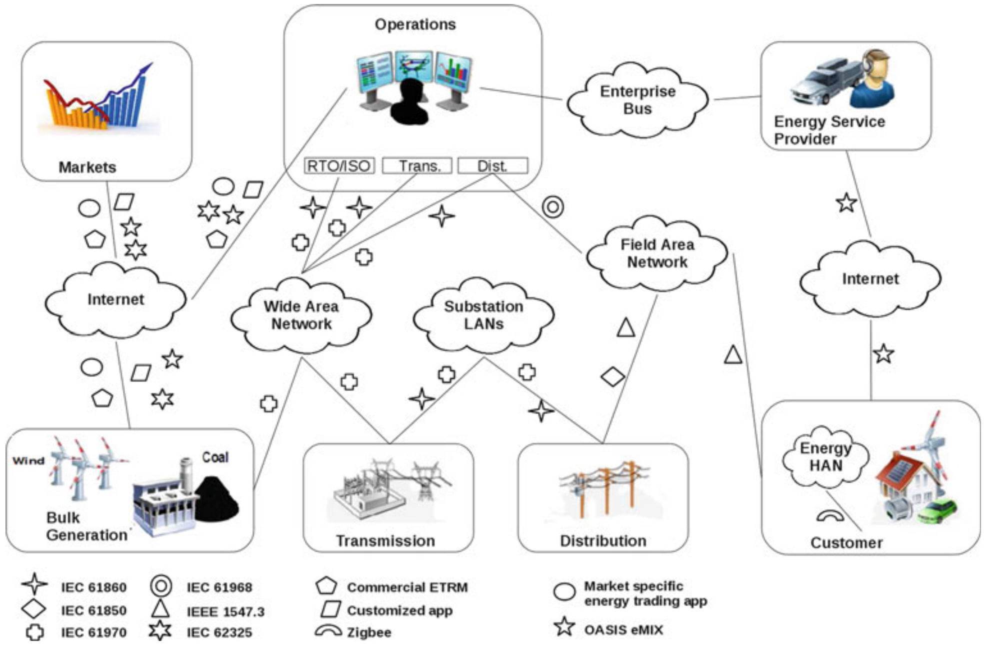

Fig. 5 Information exchange standards in Smart Grid domain

inside a distribution substation. Moreover, it details the data type to exchange with the control station where the distribution management system (DMS) is located to properly interact with the devices. In order to manage several substations containing different electrical apparatus, also coming from disparate vendors, IEC has developed IEC-61968 standard as an inter-application standard. The purpose is to let the different applications that govern the substations, or part of the contained apparatus, interact with each other at a higher level (i.e., at the software level) and then provide the appropriate control/actuation to the intended substations on the field. Regarding this, standard IEC explicitly states:

> IEC 61968 is intended to be implemented with middleware services that broker messages among applications, and will complement, but not replace utility data warehouses, database gateways, and operational stores.

The IEC-61970 is another standard bridging the gap between the physical layer and the higher levels. This standard is intended to deal with the operations of transmission systems (e.g., transmission grid), the power generation stations, the interaction with supervisory control and data acquisition and energy management system. The two latter systems are the key to operate energy production and transmission. The goal of IEC-61970 is to give guidelines for an Energy Management Systems Application Programming Interface (EMS-API) to enable different applications inside both the energy production control center and transmission control center to interact with each other. This standard is the most broad in its application and that is why it spans across several types of equipments and also different sub-domains of the Smart Grid framework adopt it. IEC-61970 has defined a set of packages containing all the objects that are relevant in the electrical energy business through the common information model (CIM) and the interfaces to be used for interaction through the component interface specifications (CIS).

5.2 Web services

Web service technologies have been proposed as the glue for connecting the physical layer and the upper business layer [21,33,35] though only as an XML protocol for remote invocation and not taking full advantage of the service-oriented architecture paradigm. In a similar direction, the current standardization effort IEC-61970—Part 502-8: Web Services Profile for 61970—will standardize the operations and interaction between the component systems involved in IEC-61970 through web services. At the moment, there is no guideline; therefore, to build an architecture based on this standard, it is necessary to follow the information given in other parts of IEC-61970 (especially CIM and CIS specifications) to identify the services needed and implement them. It is also worth mentioning the IEC-62325 standard aims at establish a "framework for energy market communications" to ease the interaction between the different entities involved in the energy markets. This last standard is based on the use of XML in particular the e-business version of XML known as *electronic business eXtensible Markup Language* (ebXML) since the focus is entirely on e-business between the different companies involved. Moreover, the IEC is considering the dedication of a specific part of the standard to web services to be used for all energy interactions.

The majority of standards in this set can be considered as the legacy heritage that the Smart Grid has to use in order to benefit from traditional energy generation facilities and grid operations. In the spirit of the new grid which envisions more distributed energy generating plants, especially at the distribution level and at end user level, IEEE has developed the 1547.3 standard. The main aim of this standard is to guide how to monitor, exchange information, and control data between distributed energy resource control equipment and distribution companies. It is interesting to notice that the information exchange model approved by the standard requires an "information exchange agreement" in which the communicating parties provide the services they are able to satisfy; in addition, the format of the messages is agreed and a common knowledge base (i.e., ontology) for the messages is required.

Moving closer to the end user domain in addition to the standard just described for the interaction with distributed energy resources, the user has also smart equipment that interacts with the Smart Grid. In particular, appliances in the smart house must be able to react to demand–response signals from the grid and also interact with each other or with a house energy coordinator. There are several protocols and standards in this sub-domain (e.g., ClimateTalk, OpenHAN); however, one of the most complete and up-to-date at the moment of writing is Zigbee Smart Energy V2.0. An interesting feature of Zigbee Smart Energy V2.0 is the compliance and use of CIM models developed by IEC-61968, 61970, and 61850.

5.3 Market standardization

If we move one step higher and look at the market for negotiating energy, the situation is less systematized. In Appendix, we provide an overview of the current situation of energy markets in G6 countries. Here, we consider the five most common situations, it is then up to the energy market participant and the markets he interacts with to use one of these or a combination of them.

With *market defined energy trading mechanisms,* the market operator specifies the rules and mechanisms to interact with the market. These mechanisms might not be fully automated and might require manual operations (e.g., filling forms, clicking buttons, or uploading files).

With *commercial Energy Trading and Resource Management* to interact with different markets, solutions available from commercial software companies are used to realize energy trading on several markets from a unique platform. The software is a customized application that is able to interact with some markets at the same time (energy trading features) and also with the back-end operations of an energy company (resource management features).

With a *customized application*, it is possible to interface the specific services (if any) the market provides for trading participants. Of course, each market, at least those analyzed in Appendix, has its specific format for information exchange.

The *IEC-62325 standard* is still underway at the time of writing. Its aim is to fill the gap that a global energy trading market faces at the moment. Although recognizing the differences and peculiarities of each energy market, the standard wants to set an energy market specific messaging profile based on the ISO 15000 series, which specifies the electronic business extensible markup language. The standard in addition to XML-based technologies envisions also web service technologies (IEC-62325-6xx standard series).

The *OASIS Energy Market Information Exchange* is a standardization effort to have a common way to exchange market information data. This effort, guided by the Organization for the Advancement of Structured Information Standards, aims at giving the guidelines for information exchange related to prices an tariffs to be used for energy negotiation on the market. The standard can be applied both in the customer/retail market and the wholesale market. In fact, it is general enough and at the same time provides enough information to manage complex forward contracts between energy producers, for example. In addition, the work of eMIX technical committee merges into the effort NIST is putting in developing a common specification for energy pricing and product definition information exchange.

5.4 Discussion

Analyzing Fig. 5 one notices that not every information exchange is specified by a standard. The technical and energy operation-oriented aspects are well standardized through the several IEC protocols. On the other hand, some gaps and limits are present in other parts of the Smart Grid landscape.

The interaction with the energy trading markets is not yet fully standardized. This is in part due to the different regulations that are present in different countries and also to the general limited number of participants that are allowed to participate in the energy trading market. This might be considered a heritage from the past where the players were a very limited number and the need for interoperability was limited as well. Currently, the issue is addressed by IEC with the IEC-62325 standardization process. At the same time, another effort in giving a common mechanism to exchange energy prices and contracts information is underway by the OASIS eMIX specifications. This lack of unique common method of access has been exploited by commercial companies that have developed different products to enable their users to trade energy on some energy markets.

Another evident limit is in the interaction with the end user. At the moment, there are no complete standards to enable the full interaction with the end user and its equipment both with his energy generating resources and with smart appliances (e.g., meter reading, demand–response functionalities or assessing energy production at house level). Closer to the end user, in the home area network, the interoperation of devices is achieved by generic standards such as Zigbee, while the IEEE 1547.3 standard addresses the issue of information interaction with distributed renewable generation plants. For pricing matters in the demand–response paradigm, OASIS eMIX can be applied in the tariff exchange between the end user and the energy provider or energy market.

Finally, the interaction between the actors that need to share business level information such as energy consumed by users, maintenance completion at customer side, changes in the grid properties performed on the field by maintenance personnel appear to have no specific support. The reason appears to be in the "local agreement" for company-by-company integration. The enterprise service bus [8] idea is applicable using protocols and techniques known from other domains, but perhaps there is space for a specific standardization effort.

6 Related work

The literature on the energy sector is broad and touches many disciplines. Here, we provide a survey of the most relevant research efforts with respect to the vision of an open grid and its relation with SOAs.

6.1 Energy architectures

The need for the integration of the various actors and the corresponding information systems is something that is not new and that has been under consideration since the first signals and attempts to unbundle the energy sector. Back in 1995, Dahlfords et al. [13] exposed the necessity of having a dynamic and flexible information system. They foresaw the need of companies to be able to interact with many more players than they were traditionally working with. The suggestion that appeared more than 15 years ago to have a two-way communication interaction with the metering apparatus along the grid is still very current, since it is one of the key aspects of the modern concept of the Smart Grid. Noticeable is the vision stated in the paper: "The energy market changes from a Producer *push-market* to a Customer *pull-market*," which today we could update with what we could call a *Prosumer*[5] *pull-push-market*.

[5] The term prosumer refers to an end-user that has the ability to produce his own energy and also to consume energy produced by others.

The same integration theme is highlighted by Becker et al. [4]. They stress the need for flexible and shared information systems to let the utilities operate more efficiently in the new deregulated energy landscape. The integration is not something new according to the authors, but previous attempts in the energy sector were not at all handy. In fact, sometimes the integration were made manually or made in a time-consuming way such as point-to-point techniques that require great efforts. The solution they mention, which has also become part of standards such as IEC-61970, is to use the common information model representation for devices and objects in the energy domain and use a generic interface definition (GID) to expose the APIs that can be accessed. The solution proposed for the integration of loosely coupled applications (e.g., ERP, SCADA, CRM, EMS, and energy trading) is based on a message-oriented middleware and a message broker that together enable the creation of a message bus in which the applications send and receive data; this can be seen as a predecessor of modern SOAs. An added value is given by self-describing messages for instance those encoded using XML language.

The data integration issue between the various actors and the benefit obtained by the adoption of SOA are addressed in [28]. An implementation of a web service SOA for the EMS/SCADA systems based on top of IEC standards gives several advantages combining the power system-oriented aspects (IEC defined) and the flexibility and the spread of web services that provide easier integration with other companies, reuse of existing infrastructure and smooth development of the web service environment [21,33,35]. Another use of web service technology is to work as the communication layer to enable the interaction between all the real-time agents that at different levels are present in the components of a modular and scalable architecture [37]. This design is suitable for the vision of a Smart Grid composed of a huge quantity of devices communicating electricity-related data through the Internet.

Although all these works are interesting and point out specific aspects of the interaction between energy systems, they tend to miss the vision and the evolution that might arise with a Smart Grid infrastructure. In fact, SOA in these works tend to focus on data integration inside a company or enable interoperability between different companies in the energy business value chain, but no one points out SOA characteristics for the incoming next-generation grid.

6.2 System interactions in the energy market

The financial aspects of an unbundled energy market and their relation to technology have also attracted research attention, for example, [49]. Other studies have focused on the proposal, test, and evaluation of business strategies to apply to this new kind of market to satisfy equilibrium [19,50].

From a software standpoint, these works are usually based on software agents with different goals interacting with each other, since many of the models are based on the concept of an agent trading on the market [24]. Sometimes, interoperability requirements in unbundled markets are addresses, but then the implementation follows agent-specific communication languages (e.g., knowledge query and manipulation language) [29]. To the best of our knowledge, the actual study of where the agents reside, how they interact, how these architectures would scale are not addressed in any significant detail.

In [48], an energy market operation system is proposed. The architecture described, although based on web services, does not completely clarify what are the services available for the market participants to interact with. Other solutions have been realized [3] to simulate different types of commodity markets (e.g., cotton, corn, and electricity), where general services and interoperability requirements for a SOA representation are described.

There are other less technological, but more business-oriented approaches that consider the interaction between the players acting in the energy market. For example, the e3value methodology [22] has been applied to the energy sector as one of its case studies, in particular the liberalized energy business is considered as a networked economy [23]. Although the model provides information on how and where value is added in different energy scenarios, the approach does not deal with the aspects of software architectures.

6.3 SOA and Smart Grid

The Smart Grid is also referred to as the "Energy Internet." In various works, SOAs are indicated as central to the Smart Grid, especially at the household level, to enable easy interaction between heterogeneous devices. Warmer et al. [53] stress how a service-based architecture can be beneficial in a Smart House in the new paradigm of Smart Grid. They see the Internet and web services as the key to enable the interaction between the house with its smart devices and the supply companies and electricity distribution systems operators to exchange supply bids and demand–response-related functionalities. The authors call for an ontology for the Smart Grid domain, so that the different actors can seamlessly interact with a common language. The issue related to ontology is addressed by Considine [9] who remarks the necessity of an ontology for the Smart Grid , actually referred to as "Service-Oriented Grid."

Collaboration between future Smart Grid objects, appliances, and devices in order to achieve better energy management and efficiency is the idea in [26]. The author envisions this collaboration between different entities such as energy resources, energy marketplaces, enterprises, and energy providers through web services, since they enable flexible integration without the problems due to implementation details. Each device of the Smart Grid will be "SOA-ready" exposing in a standard way the services it can provide, and at the same time, it will be able to dynamically discover services of other devices through web service dynamic discovery specifications. One of this devices is the Smart Meter , which acts as service provider for an enhanced business process in which the meter can not only provide real-time information, but also take decisions related to energy usage and consumption interacting with other services on the Internet [27].

Cox et al. [11] stress how collaboration is the essence of Smart Grid , and only through an interaction between the many actors involved, an effective implementation of the Smart Grid may be realized. Among the requirements, the authors identify as fundamental (that also appear in the NIST and Grid Wise Architecture Council stack) some aspects such as transparency, composition, extensibility, and loose coupling are presented, which are also basics for SOAs. The authors also identify the standards for information exchange to be used in the Smart Grid for some aspects such as scheduling and time functions, weather information, device discovery, and market interactions. All these elements fit in a SOA framework.

SOA is seen as the glue for the new Smart Grid that can enable both intra-enterprise interactions and can be even and more present in the inter-enterprise interactions that characterize even more the Smart Grid domain. This is the idea and the approach presented in [47] where the inter-enterprise information exchange interactions modeled in the Enterprise Architecture framework are linked with the inter-enterprise data exchange (which are based on the IEC standards) by the definition of an ontology that can map inter and intra-enterprise domains.

7 Conclusion

The energy sector is undergoing major changes, which heavily involve information technology. Given the main features and peculiarities of this sector, the paradigm of service orientation appears to be a perfect fit. In this paper, we highlighted the contact points between SOA and the Smart Grid, we have looked at relevant standards, web services initiatives, but also at how the energy markets work from the information exchange point of view.

We claim, together with many others, that SOA is "the approach" to be used for the next-generation grid. In particular, services are so flexible and easy to provide and contact that SOA can span among all the actors of the Smart Grid. The generating companies and energy suppliers can manage their information interactions through services, services are provided and requested by a Smart Meter and the same occurs for smart appliances inside the home area network.

Table 2 Main aspects of information systems characteristics for interaction in energy market in G6 countries

Market manager name	Country	# of entitled participants	Web interaction	Manual files upload/download	Web service	SOA	Proprietary/open solution	Additional features
GME	Italy	190	✔	✔ XML format	✔	✔	Open	
ISO New England	USA	422	✔	✔ CSV and XML format	✘	✘	N/A	– Possibility to use eMkt application – Downloadable utilities for automatic upload/download
PJM interconnection	USA	612	✔	✔ XML format	✔	✔	Softwares tools are proprietary, but interfaces are open	– Many software tools available – One of the most advanced market operators
Elexon	UK	226	✔	✔ format according IDD rules	✘	✘	Open to some extent	– Low-end and high-end service available – Automatic file transfer through FTP protocol
European energy Exchange	Germany	160 active members during last year	✔	✔ CSV format (for ComTrader platform)	✘	✘	Proprietary Xetra based software	– VALUES API are provided to interact with Xetra platform (APIs written in C) – Fax based documents to submit offers is also available
European power Exchange spot	France	80	✔	N/A	✘	✘	Proprietary software (SAPRI, Global vision)	– To submit data to French energy regulatory Commission, specific excel based format has to be used
Japan power Exchange spot	Japan	48	✔	N/A	N/A	N/A	Open as far as the small amount of information suggest	– Small amount of information in English – APIs for interaction with user custom application are available (no other information)

Appendix: Technologies in G6 energy markets

To better understand the current state of the software infrastructures for energy trading, we overview the available systems in G6 countries. All the markets analyzed have an operational structure very similar to each other, providing the possibility to trade energy with different time granularity (e.g., from hours to minutes) and with different time horizon (e.g., from real-time markets to year away forward contracts). In general, the energy market is similar to those for other commodities, the main characterizing difference being the constraints to always have a real-time balance between offer and demand. More differences emerge when considering the IT infrastructure. The common aspect is the use of the Internet and the possibility to interact in the market with web-based applications. However, for more complex and automatic interactions, each market has its own implementation. There is not any standardization between different markets (even in geographically close markets such as France, Italy, and Germany); therefore, companies that want to participate in several markets at the same time must, in order to make the interaction more automatic than employees filling web-based forms, develop their own set of specific applications to interface the particular reality of the market when available.

The main details of each of the G6 markets are summarized in a comparison chart in Table 2. The dimensions taken into account are:

- **Number of Entitled Participants**: the members that are legally entitled to operate in the market. This information can give a perception about the complexity and actual scalability requirements of the market.
- **Web Interface**: the presence between the mechanisms of interaction in the market of a Web-based platform (i.e., a browser or a browser like application specifically developed) that can be used by the user to enter data about the quantities of energy that are bidden.
- **Manual Files Upload/Download**: this feature enables to upload/download files, in a specific-defined format, containing informations about bids. This procedure can speed-up the work of the market participants that can prepare those files in advance avoiding forms filling.
- **Web Service**: this feature refers to the possibility of interaction with the trading platform through interfaces based on Web service technologies. These interfaces are provided by the market manager as another way of interaction in addition to the browser based interface.
- **SOA**: this feature is present only if the market enables a Service-Oriented Architecture as a result of the provided interaction functionalities.
- **Proprietary/Open Solution**: this item refers to the type of platform required for trading, either it is a proprietary solution that does not enable much interaction, or it is characterized by accessible open standards.
- **Additional Features**: other interesting aspects specific for that market manager.

By a careful look at Table 2, we notice a number of interesting facts. First, the number of participants differs considerably: Japan has only 48 participants, while in the USA, PJM Interconnect alone has more than twelve times that number of participants. The information about the number of participants gives an idea of the complexity of the information system.

The web interaction is the real constant between all the markets: every market enables the interaction through a web browser or some sort of proprietary web application. In order to ease and speed-up the operations of the trader, almost every market operator provides the upload functionalities to submit the bids, and download functionalities to retrieve the list of transactions cleared on the market. The type of these files is usually in some kind of representation, mainly comma separated values (CSV) or XML, that is also manageable easily by non-programmers. In some cases, the market operator provides solutions (e.g., FTP server) or sample applications (that can be modified or integrated in market participant software suite) to automate even this upload/download interaction.

Market operators tend to provide platforms that are open to enable interaction with participant custom software. The German and French markets are main exceptions since they use proprietary solutions. This is due to the influence the official trading platform of the German stock exchange (Xetra platform) might have on those participants that are interested in the pure financial trading of energy commodities: they can use the platform and the knowledge they already own.

The only two clear software solutions that are implementing a SOA system come from GME and PJM Interconnect. These two market operators provide extensive documentation about the interfaces that are exposed to participants through web service description language (WSDL) and specifications about the XML conventions used, by providing Schemas in XML Schema Definition (XSD) files. The other markets do not have at the moment solutions that follow this paradigm.

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