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Ontology-centric Data Modelling and Decision Support in Smart Grid Applications

A Distribution Service Operator Perspective

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Abstract **— Conventional electricity distribution grids are getting smarter by coupling operation technologies with advanced information and communication technologies (ICT). This provides a better, reliable, cost effective and efficient service to the consumer while requiring an immense two way data transfer between consumer and distribution service operator (DSO). This paper gives a brief summary of the current situation of DSOs in Turkey after the privatization of the market and also the state of operational technologies (OT) in use. The integration of OT with ICT is the first step in building a smart grid, and the decision support systems (DSS) are becoming crucial in this integration and operational effectiveness. A major component in the smart grid integration efforts is a common information model as pointed out in earlier work. We restate the case of ontologies in information modeling towards building a smart grid and present the requirements for using ontologies in smart grid information systems and DSSs.**

Keywords — Decision support systems (DSS), Electricity distribution, ICT, OT, Semantic Modeling, Ontology

I. INTRODUCTION

Smart grid is basically the conventional electricity grid enhanced and augmented with the integration of information and communication technologies using current operational technologies such as SCADA (Supervisory Control and Data Acquisition), GIS (Geographical Information System), DMS (Distribution Management System), AMR (Automated Meter Reading) and ERP (Enterprise Resource Planning). This integration enables a real time two way communications and data transfer between the consumer and DSO originating from energy generation through transmission, distribution and storage till consumption. Hence, smart grid is seen as a promising candidate for a sustainable, secure and efficient energy network.

This paper focuses on the role of decision support systems and ICT based smart energy management from DSO perspective. In section II, related work is presented. In section III, the current landscape of electricity distribution system in Turkey is described, main drivers for DSO service quality are briefly introduced and main operational technologies used by DSOs are covered. In section IV, necessity of DSS systems in smart grids are discussed. Our proposed approach is introduced in Section V, which integrates ontology centric data modeling with current operation technologies. We conclude and present the future work in section VI.

II. RELATED WORK

In this work we are proposing the use of ontologies in data and information modelling for the smart grid environments. There are already some initial works in this area. Wagner et al [1] suggests that open and royalty-free semantic Web standards (RDF, OWL, etc.) can provide the foundation for smart grid communication architecture. They identify core challenges in a semantic smart grid such as device heterogeneity, the need for data schema flexibility, large-scale complex-event processing, privacy and security [1].

Implementations of semantic data modeling and ontologies in smart grid information systems are an area of interest that started gaining popularity [2]. In one study, a software project for the demand response optimization for Los Angeles Smart Grid was designed [3]. In order to overcome this complex problem, a number of intelligent demand prediction models including different machine learning and data mining approaches were considered. Semantic modeling of the data based on the smart grid ontology of the demand response architecture was at the core of the information integration which included Advanced Metering Infrastructures (AMI) and other information sources in Los Angeles power grid.

Crapo et al. present semantic models and semantic Web technology as great enablers in system interoperability in smart grids [4]. They state that semantic models are modular and extensible; reasoners and classifiers built upon semantic models can handle logical implications; and rules can do all types of conversions, calculations and implement business logic in smart grid systems. Semantic Web technology, most importantly, increases flexibility and reduces the cost of implementation and maintainability. They also present Semantic Application Design Language (SADL), a modelling language close to natural English language they developed for defining models. Models defined in SADL are translated to OWL (formal ontology language) and these models are reasoned over using the rules that are again defined in SADL.

Zhou et al. present an integrated semantic Web information model using semantic Web technologies, and specifically OWL and present case studies using semantic

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information for dynamic demand-response [5]. As for future work, they propose transforming smart grid standards to semantic Web ontology representations. It is stated that they are developing a Complex Event Processing Engine for dynamic demand response.

Ontologies and semantic Web technologies are great enablers for decision support systems (DSS) that are widely used in the grid systems. Smart grid systems with ontology-centric DSS systems will be much more capable in terms of dynamic management and demand-response optimization.

There are industrial standards called IEC 61850 and IEC 61970 which build the basis of semantic services and modeling unified Smart Grid ontology. IEC 61850 device model standard constitutes modelling for describing device functionalities in the grid and it defines configuration and runtime exchange data between devices. IEC 61970 power system model describes the behaviors and attributes of utility's operational systems in which a type of UML (Unified Modelling Language) called Common Information Model (CIM) is described for power system semantics required by various power utility applications. [6]

Smart grid management with full of active players needs an artificial intelligence and decision support systems providing solutions for distributed energy resources and demand response. Context awareness should be created by taking the right decisions must be taken according to characterization of the situation. Vale et al. describes a case study for Virtual Power Players (VPP) and multi-player negotiation in the context of smart grids, aiming at optimizing energy resource management, considering distributed generation, storage and demand response. [7]

III. ELECTRICITY DISTRIBUTION IN TURKEY

A. *Concept of Electricity Distribution Operations in TURKEY*

Energy is considered as one of the most important indicators for enhancement of welfare. In this respect; Turkish Government, perceived privatization in electricity sector as the main driver to launch liberalization and sustainable economic development. In 2004, Strategy Paper was published as an important milestone. The guidelines of privatization, the tariff system and divided distribution regions are some of the important topics, announced with this paper [8]. According to technical and financial factors, namely managerial structure, energy demand, geographical proximity, the distribution network of Turkey is divided into 21 distribution regions. The privatized distribution companies are responsible only for distribution activities. Enerjisa pioneered privatization in electricity distribution sector by taking over Başkent Electricity Distribution Company in 2009 and later Ayedaş and Toroslar Electricity Distribution Companies in 2013 [9].

B. *Main Drivers for Quality of Service*

Due to vertical unbundling in Turkey, Retail Company and Distribution Company are separated from each other. Distribution companies are responsible for the quality of service they provide to users in the region determined by distribution license and last resort supplier is responsible for commercial quality of retail sale activity. Therefore distribution companies are audited by EMRA (Energy Market Regulatory Authority) regulations for continuity of supply which are driven by the metrics (1) System Average Interruption Duration Index (SAIDI), (2) System Average Interruption Frequency Index (SAIFI). Another metric for the continuity of supply in the following years will be Customer Average Interruption Duration Index (CAIDI) and distribution companies started to modify and integrate their SCADA, GIS, AMR and ERP systems to detect which customer is exposed to outages accordingly. In addition to regulations for the continuity of supply, the distribution company is liable for meeting operation conditions for voltage imbalances, voltage harmonic values, flicker and reactive energy which affect the quality of electrical energy [10]. There are several operational technologies currently in practice in order to achieve quality targets and they can be further improved in ontology based architecture.

C. *Operational Technologies used by DSOs*

SCADA monitors and controls substations, transformers and other electrical assets. SCADA/DMS (Distribution Management System) enables DSOs to collect, store and analyze distribution network data from substations, performs grid modeling, simulates power operations, pinpoints faults, and preempts outages. Outage Management System (OMS) is a grid management software application that typically includes functions such as trouble-call handling, outage analysis & prediction, Work Force Management (WFM), and reliability reporting. OMS tightly integrates with call centers to provide fast, accurate, customer-specific outage information, as well as SCADA systems for real-time-confirmed switching operations. These systems track, group and display outages to safely and efficiently manage service restoration activities. GIS plays a very important role in DSOs for mapping the information of high and low voltage consumers and electrical grid assets, on a geographical base map, to help in defining the consumer's electrical connectivity. ERP system is defined as a business management software package that enables the sharing of business information stored on a common database among targeted business units in the entire organization [11]. The purpose served by an ERP system is that of organizing, codifying and standardizing the business processes and information or data. AMR is the system that remotely collects the consumption data from customers' electric meters using various communications technologies and processing the collected data for billing and other decision purposes [12]. In order to reach successful smart grid deployment, integrations of above systems are needed.

IV. NECESSITY OF DSS IN SMART GRID

A. *Benefits of System Integration*

Integration is the powerful way to success harnessing the flood of knowledge created and turning it into real-time business intelligence. Distinct systems manage distribution system operations efficiently; the role of each system is different and unique. The SCADA/DMS - GIS interface helps meeting the requirement of electricity distribution companies looking for new ways to optimize their field operations, increase workforce efficiency and the business processes. Integration of GIS with AMR and SCADA/DMS leverages modern computing capabilities to distribute extremely valuable information to a wide range of customers, while meeting the electricity distribution company's increasing need for real-time information. Integration of GIS and OMS allows reported outages to be mapped on the GIS system for an accurate fault location of the field equipment (e.g. breaker or switch). OMS calculates the approximate source of the outage and accelerates determination of fault location. Integration of OMS with Interactive Voice Response (IVR), SCADA and ERP helps customers identifying the probable fault location based on trouble calls. OMS analyzes information from trouble calls to narrow down and predict the fault location [13]. Integration of AMR and OMS allows for outage data to be recorded in the OMS based on the status of each customer's meter rather than customer phone calls. Proposed integrations scheme is given in Figure 1.

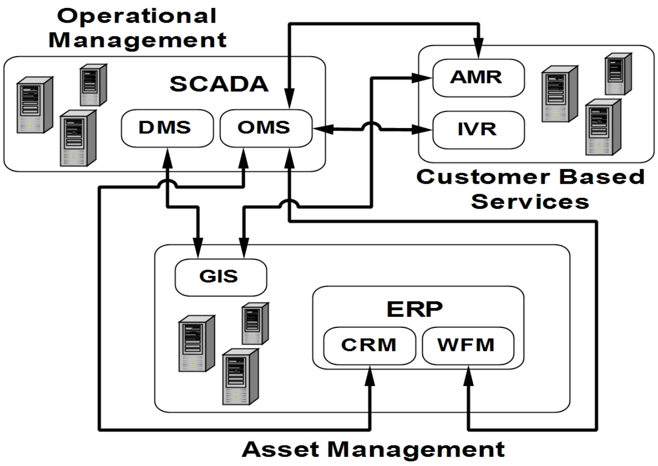

Fig. 1. Proposed System Integration

The operational effectiveness in the above mentioned integration can be improved by limiting data redundancy, streamlining workflows, reducing costs by avoiding duplicate systems and processes, enhancing decision-making and responsiveness. Thus, DSOs will have greater visibility in system operations. Each DSO has unique integration models and methods because of different regulatory rules, market contexts, business plans and strategies.

Smart grid projects are large and complex, with challenges that require much more than selecting vendors and buying products. Electricity distribution system integration requires considerable investments in software, hardware and development, depending on the business, scope of integration and requirements. Towards achieving a smart grid a DSO's first step must be improving IT/OT integration and infrastructure. IT systems are operated by software applications for commercial decision making, planning, business resource allocation and process management. OTs are based on software applications for providing operational real-time or near real-time control of grid assets. “Integration” is defined as the approach of making two or more independently designed systems, databases or processes that work together to achieve a common business goal [14].

Enterprise Service Bus (ESB), is a key element in the integration architecture for set of standards-based and secure domain services. An ESB provides an infrastructure view that manages the run-time business and infrastructure services which facilitates from existing assets. Though Service-Oriented Architecture (SOA) and ESB are central to deliver these capabilities, DSO is looking towards business process management and complex event-processing technologies as critical components necessary to deliver this value. The key benefits of an integrated approach of OT and IT business systems can be listed as reduced operating and working capital expenses, increased reliability and operating revenue, service consistency, fulfillment of customer expectation, quality of service and regulatory performance [15]. To benefit from system integration, information and system interdependencies must be well defined.

B. DSS in Integrated Distribution Operations Regarding Future Deployments and New Challenges

Electricity distribution operation management faces complex conditions which need fast decision making and often strain cognitive capabilities of operation personnel who are using the standalone and integrated systems.

In parallel to developments in various technology domains, the conventional scheme of electricity distribution has started to alter within the frame of a new power flow paradigm. Installations of DG units have gained acceleration throughout the distribution grid. Most common types of DG installations have been solar photovoltaic panels mounted on rooftops of households or commercial buildings with available roof space. Additionally, micro combined heat and power (μCHP) units and small-scale wind turbines are becoming increasingly viable options according to the customer-specific requirements and local constraints of the installation site. Increased grid integration levels of DGs conflict with the conventional power system design of unidirectional power flow towards the customers connected in low-voltage grids.

Moreover, installed units are not owned by the DSO; leading to lack of monitoring and control capabilities over the DG units. An increase of interest inevitably leads towards increased number of DG installations, which spreads the incapability of DSO for DG monitoring and control throughout the distribution grid. Similar to the increased interest in DG, EVs also carry the potential risk for the current infrastructure. EV charging requires alternative infrastructure designs and various electrical standards exist in different use cases [16].

Distributed Generation (DG) and Electric Vehicles (EV) charging behaviors will affect service quality of the grid. Meteorological conditions, social behaviors and electricity price signal play a certain role for DG and EV regarding peak consumption. All investments are applied to provide uninterrupted service to meet peak consumption. These conditions are increasing due to the fact that global need for energy is rising while energy sources will not meet this need. Therefore in order to manage energy supply in an acceptable manner, DSS for energy management emerged. DSSs play an important role in smart grid by intelligently integrating the actions of all connected users for delivering sustainable, economic and secure electricity supply [17].

For an efficient and safe operation of electricity distribution grid with high penetration levels of DG and EVs, ICT integration and standardization are of critical importance. Within the scheme of a dynamic electricity market and dynamic pricing mechanisms in order to improve the market efficiency, resource aggregation emerges as a sound method of market participation for small-scaled energy generation. Within this perspective, the concept of Virtual Power Plants (VPP), has matured and corresponded with the existing market paradigms. VPP is defined as "being composed of combining various small size distributed generating units to form a single virtual generating unit that can act as a conventional one and capable of being visible or manageable on an individual basis" [18]. The same framework can be adapted to any aggregation of distributed energy resources integrated to the grid and can be conceptually customized for applications of vehicle-to-grid (V2G), demand response and smart building management systems. However, physical integration of developed concepts eventually requires a set of standards for interoperability in order to maintain a reliable, safe and efficient grid operation. Required level of sophistication increases both for the grid operators and active 3rd party entities (i.e. VPP operators). A variety of information sources need to be evaluated; including but not limited to weather forecasts, grid or generator site conditions, load and generation levels.

Such sophistication can only be handled with accurate and extensive information models and customized DSS for all commercial and technical entities. Usage of different protocols and standards causes the problem of interoperability and intercommunication among all systems. Missing or misinterpreted pieces of any information have the potential to cause all kinds of operational problems. Therefore, it is of critical importance that information modeling frameworks and standards for DSSs are developed and globally compliant.

Furthermore, data processing needs of these systems are enormous. They need to integrate data coming from many partners: consumers, producers, and now prosumers (consumers acting like producers), and their relevant systems. Moreover, the variety of data interchanged among these partners is very high depending on their profiles, needs, requirements, and constraints.

V. ICT Based Smart Energy Management Infrastructure

A. Communication Infrastructure

Smart Grid communication network is divided into various segments including home area network (HAN), serving nodes within consumer premises; neighbor area network (NAN) connects meters and collectors; Local Area Network (LAN), serving smart meters, sensors, capacitor banks, voltage regulators and wide area network (WAN), DSO's core backhaul network [19]. Depending on the consumer type the HAN could also be named as building area network (BAN) or industrial area network (IAN). The electricity distribution grid is operated, controlled and monitored using ICT, as a complex system, each network area (WAN, LAN, NAN and HAN) has different communication requirements, therefore they employ different technologies [20]. End-to-end smart grid communication infrastructure shall be reliable, manageable, scalable, modular, future proof, cost effective, vendor independent, standards-based, interoperable and secure.

B. Information Modeling

Today's information systems are much more complex than their predecessors; they store, process, retrieve and distribute more data and information. The modern information systems are also more integrated than ever due to the Internet revolution; they are interconnected and intra-connected all the time. Timely information processing and real-time monitoring are very critical for many systems. Therefore, in short, information systems and their data modelling requirements are very complex. Overcoming this complexity requires novel ideas and new techniques.

Early information systems in this area adopted classical information models, namely the relational data model as it is still the dominating industrial standard. However, relational data model, although very efficient in modeling and querying, has its own deficiencies in capturing the complexity and evolution of semantics in data models.

Here an ontology-centric data modeling perspective for smart grid information systems is presented. Many complex information systems resort to this solution because of the complexity of data modeling requirements and the need for information extraction. Due to these requirements systems move from standard relational data model to information-centric ontology modeling. Relational data modeling has been very successful in transforming information systems in the last four decades; now most information systems are running on this model. However, as the data complexity, data variety and data size increases relational database systems are becoming an obstacle for today's information systems. One of the major problems in relational database-based systems is the growing need for change and evolution in data model. Data model changes in these systems are difficult to handle. It requires changing software as well that processes the data. Think about adding a new data column to a table in a database. This requires changing the data model, which is updating the schema, modifying SQL queries that access, update, delete that table, and also changing software pieces such as Web pages, server side data processing software, etc. All these changes are costly and for time-critical complex systems the change needs to be done in Internet-time.

Constructing good relational data methodologies for smart energy management systems such as the one in this study also provide easier model development environments for other application areas dealing with smart grid and energy distribution data, such as distributed control, generation and demand forecast, demand response [21]. An ontology based data modeling can be an appropriate solution to these challenges.

Ontologies provide a more convenient solution for many complex systems such that (1) their data model changes frequently, (2) they need information reasoning capabilities to deduce new information from raw data or already extracted information based on rules. Ontologies are now more frequently used in health information systems, production management systems, DSS, etc. [22]. Smart grid systems, due to the data modeling and information extraction needs, are a good candidate for ontology-based information system support. Ontologies, semantic Web technologies (a related topic for ontologies), data modeling and data access standards based on ontologies and semantic Web, rules and rule languages, and the use of these technologies in smart grid information and DSS are introduced below.

C. Ontology

According to Gruber, ontology is a specification of a conceptualization [23]. That is, ontology is a formal description of the concepts and the relationships between these concepts in a certain application domain. For example a domain ontology in health care describes concepts like people (doctors, nurses, lab technicians, patients, etc.), diseases, operations, medicine and the relationships between objects such as a certain medicine “cures” certain diseases, etc.

In the case of smart grids, ontologies provide an appropriate tool to model complex data and information artifacts. Smart grids are complex systems with a wide variety of subsystems, parts, and many interconnected components. For example, a micro grid in a larger smart grid system is a complex subsystem itself; it has power generators, consumers of all types, producers of different types, smart homes and their differing profiles, demand side balancing systems, etc. Data model is the backbone of all information and decision flow in this complex system. Therefore, it requires utmost attention from the beginning and the data model needs to be kept up to date in all cases. Any change in the data model should be reflected in the software and systems. Such data modeling and change management requirements are difficult to handle in classical relational model-based database systems; ontologies offer a flexible and richer data modeling method.

Ontologies are not only better in data modeling but also offer a better option in data integration. In smart grid systems, ontologies can be used to integrate data from many different systems (weather, smart homes, traffic, utilities, etc.) semantically [24]. A general model for ontology based smart grid information system is depicted in Figure 2.

Over the years many languages are proposed for the formal specification of ontologies. With the advances in Web technologies, and greater need in information definition and integration, ontologies came to the area of the Web and OWL[1] became the standard language for ontology definition. World Wide Web Consortium (W3C) determines and issues OWL and other related ontology standards including RDF and RDFS, and the standard query language SPARQL in the Semantic Web[2] domain.

As we pointed out shortly in related work section above, using ontologies in smart grid environments is going from a mere proposal [1] to a reality, for example as in in Los Angeles Smart Grid project [3] and other similar projects [4, 5].

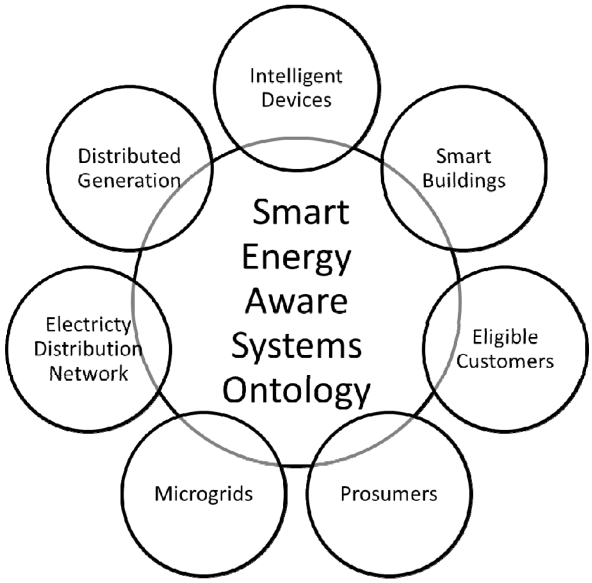

Fig. 2. The role of ontology in smart grid systems2 .

D. Relation of Ontology and Rules to DSS in Smart Grid Stakeholders

DSO is the direct physical interface that responds to all the electricity demand. This scenario is analogous to retailers acting like banks such as people make money transactions from one bank to another without touching the money physically, likewise DSOs are like ATM machines creating physical interface. Demand Response can be realized by demand side management which DSO can offer to customers to dispatch the permitted load from grid and this demand can act as a negative generation. DSO needs DSS in order to manage which loads can be dispatched, which DG units will supply electricity to grid and creating a knowledge model by giving acceptable recommendations regarding meteorological conditions, price signal and social behaviors rapidly changing in time; as a whole realizing demand response. These DSSs are supported by SCADA, in which the energy supply is monitored in real time; provide context awareness to SCADA for achieving a new smart SCADA philosophy requiring two new paradigms: Cyber-Physical Systems (CPS) and Multi-Agent Systems (MAS) [7].

CONCLUSION AND FUTURE WORK

DSS is crucial for an effective and sustainable smart grid infrastructure and is key to making objective and sound decisions in less time both for private companies and regulatory authorities. Moreover, ICT based smart energy

[1] OWL, http://www.w3.org/TR/owl2-overview

[2] Semantic Web, http://www.w3.org/standards/semanticweb

management will enable improvements in service quality, efficient consumption of resources via smart resource planning and increasing context awareness. Since electricity sector is evolving with ICT in order to build a smart grid, it is inevitable that DSSs and the new information modeling standards will directly affect and help all the stakeholders of the sector in taking the right decisions for more efficient energy generation, distribution and consumption.

We, at Başkent Electricity Distribution Company, are participating in the Turkish consortium of Smart Energy Aware Systems (SEAS)3 project under ITEA2 program. The SEAS project is tackling the problem of inefficient and unsustainable energy consumption by enabling the interworking of energy, ICT and automation systems at consumption sites, introducing a dynamic and intricate ICT-based solution to control, monitor and estimate energy consumption. Additionally, business models and solutions will be explored to enable energy market participants incorporate micro grid environments and active customers in smart energy buildings by way of building a new knowledge model and information exchange platform using ontology-based semantic context modelling.

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