A Knowledge Management Platform for supporting Smart Grids based on Peer to Peer and Service Oriented Architecture technologies

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Abstract— **In Smart Grids the design of a common management platform that integrates and coordinates grid protection and business services such as commercial supply-demand matching, is clearly one of the challenges ahead. The work presented in this paper provides a framework of knowledge management mechanisms in order to support a Smart Grid. We present the design and implementation of a platform that supports the knowledge management needs for applications such as power system operations and power system reliability in the Smart Grid environment. Both applications are modeled on the same service oriented platform.**

Keywords: smart grids, knowledge base, power grid, service oriented architecture

I. INTRODUCTION

Power Systems are supposed to go through a radical change in the next few years [1]. The growing presence of Distributed Generation (DG) and in particular the introduction of renewable sources is expected to significantly change the Distribution Networks. So far, electrical energy generation traditionally was based on large concentrated power plants. Reducing the carbon footprint and finding new and more efficient ways of producing and delivering power are fundamental drivers behind the overall take-up of distributed generation.

Furthermore, according to the new energy deregulation laws, energy consumers are now in the position to also produce and trade energy [2]. Also more players are authorized to produce, deal and transport energy. With the liberalization of markets and the spreading of local, distributed and renewable energy resources, utilities are considering a more active involvement of the customers through the features of Smart Metering. Advanced sensing and measurement technologies provide a global and dynamic view of the power system and automatically checks if predefined operating limits are violated [3]. This new infrastructure, briefly called Smart Grid (SG) drives significant increases in the efficiency of the electrical grid and empowers consumers to manage their energy usage through Demand Response (DR) [4]. Additionally it enables the integration and optimization of more renewable energy as well as plug-in electric vehicles. Smart Grid, presents an unbreakable connection of power, control and communication systems.

The above changes are anyhow bringing some interesting new challenges in the energy sector. Due to the growing complexity and interdependency, today's top-down hierarchical management of the grid no longer meets the modern requirements [5].

Centralized decision making for power unit commitment planning and vertical, closed and hierarchical SCADA (Supervisory Control and Data Acquisition) systems have to be replaced by more flexible information systems. Tomorrow's grid needs decentralized and more intelligent ways for information, coordination, and control. To achieve this, Information and communication technologies (ICT) is a crucial ingredient. Established ICT technologies, Information Model standards and associated Service Oriented Architectures, are capable to cater for many of the functionalities of distributed energy networks [6], [7]. They enable new electronic services based on two-way communication between suppliers and customers. Automated demand response, balancing services, and dynamic pricing, buying, and selling of power in real time, applications of energy storage, are just a few of the new services due to the application of advanced ICT.

In Smart Grids the design of a common management platform that integrates and coordinates grid protection and business services such as commercial supply-demand matching, is clearly one of the challenges ahead. The mechanisms for security and dependability must be able to work both at the level of technical grid operations and the level of supplier-customer business processes. In addition the models to be used must be capable of accounting for uncertainty present in the power system due to the intrinsic uncertainty of the renewable sources, the instantaneous power output and the electricity flows created by the liberalized market.

In this work we aim to provide a framework of knowledge management mechanisms in order to support a Smart Grid. We present the design and implementation of a platform that supports the knowledge management needs for applications such as power system operations and power system reliability in the SG environment. Not all SG applications but only a limited subset of priority functionalities are studied and analyzed. The rest of the paper is organized as follows: section II introduces the requirements imposed, both for distribution and trading of power in the future grids. Section III discusses the information management requirements and the proposed information management platform to achieve interoperability of smart grid systems. Section IV presents the case studies considered for the evaluation of the proposed model. Section V concludes the paper.

II. Requirements For Distribution And Trading

Grids must provide all consumers with a highly reliable, cost-effective power supply, fully exploiting the use of both large centralized generators and smaller distributed power sources. In the future the distributed energy production will play a major role. These energy production methods have in common that many small capacity power plants supply power to the grid. Operation of the system will be shared between central and distributed generators.

Disturbances in the equilibrium between power generation and consumption manifest themselves in deviations from the mandatory voltage frequency. These deviations can be compensated by application of balance power. Distributed Energy Sources (DER) should actively participate in the grid control (frequency, voltage). This is the necessary step towards a full equal status of DERs and towards a true liberalization of the energy market. The electric distribution system may be arranged in a variety of structures. Distribution actors may have local inter-device (peer-to-peer) communication or a more centralized communication methodology. Actors perform services to support processes of the power system. Most DERs are served through aggregators by establishing co-operations between several smaller power sources. Aggregators combine smaller participants as providers or customers or curtailment to enable distributed resources to play in the larger market. The information model that supports the knowledge management needs in the SG environment has to meet the technical and legal conditions to allow common acting of these market participants [8].

Since grids have to deal with input from many distributed, small, and to a large extent heavily fluctuating producers, the establishment of localized clusters of plants for scheduling, controlling and monitoring of the system is more effective than a grid management based on a central platform. On the other hand, demand side actors may be suppliers as well as consumers. Private households, farmers and small industries become power producers as a result of the distributed nature of the production. The quantity of power exceeding the internal demand can be marketed. For this target group, energy marketing is not the central activity. Therefore, suitable solutions should allow automatic trading to a large extent. The electricity grid will be interactive for both power generation sources and power consumption loads. The establishment of localized clusters and the cluster levels to be implemented can depend on various constraints. Targets of optimization could be reliability and availability, the minimization of losses, economic aspects, risk and stability criteria or various economic or ecologic interests. Clusters of producers or consumers can be organized in a hierarchical order and the communication can be routed over different hierarchical levels.

Taking the above requirements into account, suitable architectures for trading and distribution must be proposed. Active distribution network technologies enable Virtual utilities (virtual electricity market) where power is purchased and delivered to agreed points or nodes. Control of distributed generators could be aggregated to form microgrids or Virtual Power Plants to facilitate their integration both in the physical system and in the market. Virtual Power Plant (VPP) approach must first of all be based on a physically stable control power system. It cannot be created by only static economic balancing models and accounting strategies. By using peer-to-peer (P2P) solutions, crashes of single systems (peers) can be compensated by others and do not disturb the overall system stability. In a super-peer hierarchical architecture, super-peers coordinate and control lesser peers. Super-peers submit orders to their subordinate peers. Crashes of super-peers can be compensated by other super-peers. Control is being distributed across nodes spread throughout the system. Distributed real-time control is difficult to access and it is critical given the need for power balance at any instant in time. Interoperability is critical for system control. For the power grid and its requirements, super-peer architectures pose the best solution [9], [10], [11].

There is a need for consistent data models as well for a both vertically and horizontally conceptual integration system throughout the various levels in the power grid. This would serve reliability, efficiency and trading. The National Institute of Standards and Technology (NIST) Smart Grid Conceptual Model forms a common representation of information for SG [12]. It is a tool that provides a context for analysis of interoperation. The conceptual model consists of several domains, each of which contains many applications and actors that are connected by associations, which have interfaces at each end. The domains of the SG according to the conceptual model are Customers, Markets, Service Providers, Operations, Bulk Generation, Transmission and Distribution domains.

SG distribution management monitors, controls and coordinates the operation and supply of the electrical power system in which participate Distributed Generation (DG), Demand Response (DR), Electric Storage (ES) and Plug-in Electric Vehicles (PEV) applications. Communication between Markets and Distribution effects localized consumption and generation. In turn, behavioral changes due to market forces may have electrical and structural impacts on the distribution domain and the larger grid. DR and DG enables peak load management by economic incentives. Energy customers and distributed producers develop a variety of strategies to respond. For example dynamic pricing service collects energy bids from DER and combines those bids into an aggregate bid into the market operations bid/offer system. When accepted the service notifies the end customer/producer of the status and requests scheduling. ES application allows storage to participate in DR. Mass deployment of PEV is difficult since there are very special issues to consider when designing for massive PEV support. In addition to PEV management, distribution operations need information on when, where and how fast they are charging.

Distribution Management System (DMS) monitors in the real time and controls the distribution system, on a node-by-node basis, based on operational parameters constraints, system topology, operator control decisions and real price energy prices. It calculates the optimal settings of power and voltage, monitors the real time capacity from SCADA, the available distributed generation capacity and the available customer dispatchable loads and takes corrective actions. The integrated system monitors the behavior of distribution operations under normal and abnormal operating conditions. Such system requires advanced hardware and management protocols for connections, whether for suppliers, for consumers or for network operators.

Applications within the domains are derived from the Common Information Model (CIM) standard developed by the electric power industry. The CIM standard, adopted by the International Electrotechnical Commission (IEC), defines a common vocabulary and basic ontology for aspects of the electric power transmission and distribution and allows application software to exchange information. The IEC series of standards (IEC 61968, IEC 61850, IEC 61970, IEC 60870) provide the required features to serve as a communication standard in accordance with the criteria of maximum latency time assigned to each class of information defined for each active component of the network. Related applications include distribution management system, outage management system, planning, metering, geographic information system, customer information systems and enterprise resource planning [13].

III. The Proposed Information Management Platform

The proposed Knowledge Management Platform supports the knowledge management needs for applications such as power system operations and power system reliability in the SG environment. Both applications are modeled on the same service oriented platform.

We propose a Peer-to-Peer (P2P) framework based on decentralized production, trading and storage of energy. Since the SG's entities are independent and their Knowledge Base contents are evolving we adopted an ontology-based P2P metadata management system for designing a virtual network, where peer software entities implement distributed algorithms for the localization of remote energy providers and peer control centers. The proposed approach has many advantages, both technical (availability, robustness, scalability) and socio-economic (improved efficiency, reliability and competition). The framework and the architecture are based on the Model Driven Architecture (MDA) of the Object Management Group (OMG) and specifications following the National Institute of Standards and Technology (NIST) Smart Grid Conceptual Model for information modeling [14], [15], [16].

Furthermore, the proposed framework undertakes the representation and handling of the fuzzy information involved by using the fuzzy sets theory. There is uncertainty in many aspects of the power grid due to the intrinsic uncertainty of the renewable sources, the dynamic instantaneous power of the grid and also due to the use of imprecise and vague terms or even the lack of information while stating incorporating criteria like environmental impacts, operation condition history, maintenance scheduling and alternative supply availability [17]. Fuzzy set approach provides more natural means for a planner to express his preferences in a form of a query containing fuzzy terms and permits the user to specify the precision with which the conditions involved in a query are satisfied.

The proposed energy sharing strategy assumes that users are also owners of power generators, and control is distributed. The customer physical network layer consists of connected nodes, each one equipped with small power generators using renewable forms of energy and controllable loads, sensors and a computing unit. We consider microgrids in which consumers and producers are able to share information about their status (energy needs/offerings) with the help of a distributed software application that creates the overlay network layer. A node that produces energy may consume it immediately, store it or transfer it in the system, in order to fulfill the needs of another node (inside the same microgrid, or outside). When a peer requires an amount of energy, it starts searching the overlay P2P network for a possible provider. Many available providers may be discovered. One or more providers are selected, in order to reach the required energy amount. Selection is based on criteria related to supply-demand balancing, reliability and price. Considering the whole grid, nodes in the overlay network layer can be thought of as being connected by virtual or logical links, each one corresponding to a path, maybe through many physical links, in the underlying computer network.

Finding the most suitable overlay network scheme is a challenging task, requiring expertise in both distributed computing and artificial intelligence. The placement of information about shared resources plays an important role in the characterization of a P2P overlay scheme. To improve the performance (with respect to scalability, lookup performance and stability) of P2P networks, layered overlay schemes have been studied and implemented. Such overlays are characterized by interacting layers, each one being organized according to one of the "flat" models (Hybrid Model, Decentralized Unstructured Model, or Decentralized Structured Model) [18].

In Fig. 1 we illustrate how entities in the overlay schemes are organized. The conceptual model is represented as a UML class diagram. The *Customer* class generalizes two subclasses of end users; the *Consumer* and the *Producer*. The class attribute *is_prosumer* guarantees that a customer instance may have a dual role. In the physical layer each customer acts as an autonomous peer able to provide a number of services. The *BulkGeneration* class also generalizes two subclasses; *Conventional* and *RES* (Renewable Energy Sources) resources and aggregates a number of customers. Customers are also aggregated in *Local Distributions* that can be hierarchically organized. Again in the physical layer *LocalDistribution* instances act as aggregator peers that host various type of knowledge including the history of previous utilizations of its customers. The *OperationBalancer* is the core class in the model that is associated with all the other classes in order to aggregate all the needed type of information, process it to obtain the knowledge that is necessary in order to balance the system, guarantee security as well as to signal prices to the

Market. Through its association with *LocalDistribution, OperationBalancer* may be also organized in logical hierarchies. We foresee three abstract classes; namely the *Service Provider,* the *Market* and the *Transmission* to indicate the actual perspective; i.e. the market that is composed by many service providers and that utilizes a number of bulk generations.

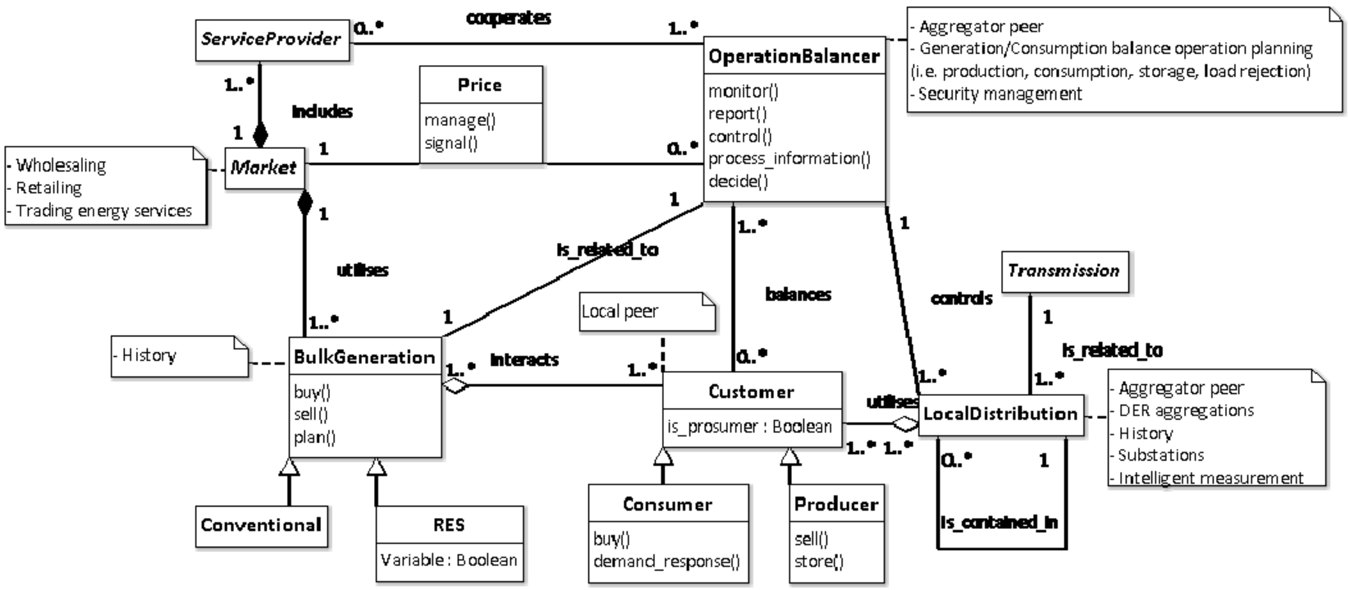

Fig. 1. The conceptual model of the proposed knowledge management platform represented as UML class diagram.

IV. Case Study

In order to evaluate the implementation of the proposed information management framework the electricity power system of the Crete Island is chosen. Crete is currently the largest autonomous system in Greece with the highest annual rate of increase nation-wide in energy demand (about 5%). In 2010 the peak load was about 632 MW and the annual demand was 2.86 TWh. The load curve is characterized by large daily and seasonal variations (summer and evening peaks). The load factor of the system is usually low due to high peaks of short duration occurring during the summer (high tourist season) and low valleys during the rest of the year. The conventional generation system consists of three thermal power plants of total installed capacity of 817 MW in three power plants Chania, Linoperamata and Atherinolakos. Twenty five central thermal units of various types are installed, i.e. slow steam turbines, combined cycle units, diesel units and gas turbines. Steam turbines constitute 48% of the total thermal power installed capacity and are characterized by high production cost. Currently, as being an isolated system, there is no real market operating.

Instead a ‘‘Single Buyer” organization is operated by the Public Power Corporation (PPC) of Greece. Currently, there are Wind Farms (WFs) in operation with a total capacity of 175 MW and 52 MW Photovoltaics (PV) installed. The contribution of Renewable Energy Sources (RES) reached approximately 22.7% of total energy demand during 2010 [19]. This high RES activity has been encouraged by the very favorable wind conditions prevailing in the island and the attractive policies undertaken. Also satisfactory fixed feed-in tariffs are set under present regulation in Greece. Extended gradual development of the RES is in progress, requests for future RES production of 3.5 GW are currently considered by the Regulatory Authority for Energy (RAE), as a result of the scheduled interconnection of Crete with the mainland grid. Moreover, a well-structured transmission grid characterizes Crete (depicted at Fig. 2), consisting of 150 kV and 66 kV overhead lines, and a good on-line monitoring system. Under this regime, Crete is a system of very high wind penetration.

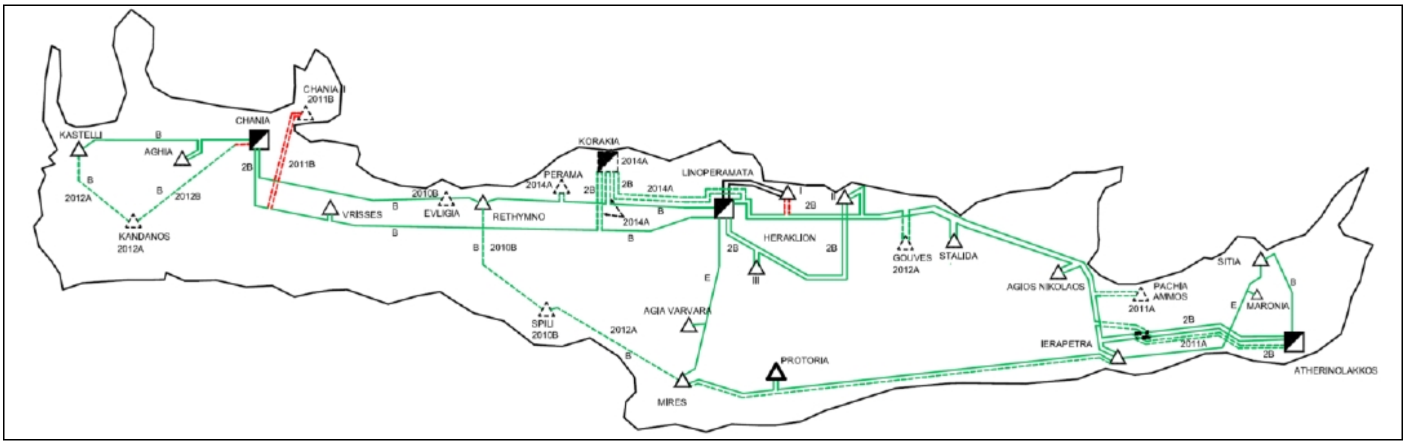

Fig. 2. Production and transmission system of Crete for the period 2009 – 2013.

In order to cover a scope as broad as possible, but also considering that a dedicated analysis for the whole system would require much more data and time, different scenarios were selected for the case study in Akrotiri area. The local peak consumption demand in Akrotiri area is 30 MW. The Akrotiri distribution network includes different load profiles (industry, shopping center, business center, households, rural farm) connected to medium/low-voltage (MV/LV). According to different scenarios the system connects 15 MW of various dispersed and renewable energy sources of different technologies (Combined Heat and Power, PV, Wind) as well as storage units. Active power balancing is enabled through the dispatch of power generation, storage and controllable loads in the framework of VPP and the provision of system services such as demand side management, congestion management, power and voltage control and islanded operation. Load control performed with a specified controllable load level. As the decentralized energy management into the system is not applied to today's practice of distribution system operation, no real data were available. A set of assumptions and projections on key parameter values were made. To make our scenario assumptions plausible they are based on related historical data, outcomes of related studies and expert judgments.

The model of the proposed knowledge management platform has been implemented by means of DEUS [20], a general-purpose tool for creating simulations of complex systems that programmatically allows the implementation of nodes (i.e. the parts which interact in a complex system), events (e.g. interactions among nodes) and processes (they regulate the timeliness of events). Currently the algorithms for reliability and trading capabilities as well as the related node services are being implemented and system is populated with real data that represent the Akrotiri distribution network. The next step is to define a set of metrics in order to evaluate the above mentioned applied algorithms.

V. CONCLUSIONS

We argue that the shift from centralized power plants to distributed generation may be one of the greatest innovations of next decades. To achieve this established ICT technologies, Information Model standards and associated Service Oriented Architectures, are capable to cater for many of the functionalities of distributed energy networks. For that we propose a Peer-to-Peer (P2P) framework based on decentralized production, trading and storage of energy. The framework is augmented with knowledge management support for applications such as power system operations and power system reliability. The implementation of the proposed information management framework is being evaluated in the electricity power system of the Crete Island, currently the largest autonomous system in Greece with the highest annual rate of increase nation-wide in energy demand where the contribution of Renewable Energy Sources is quite high.

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