A Generic Ontology for Prosumer-Oriented Smart Grid

Syed Gillani
Telecom Saint Etienne,
Université Jean Monnet
Saint Etienne, France
syed.gillani@univ-st-etienne.fr

Frederique Laforest
Telecom Saint Etienne,
Université Jean Monnet
Saint Etienne, France
frederique.laforest@telecom-st-etienne.fr

Gauthier Picard
Institute Henri Fayol, EMSE
Saint Etienne, France
gauthier.picard@emse.fr

ABSTRACT

The concept of Smart Grid (SG) has comprehensively overhauled the scene of electric power grid and the integration of *Prosumers*, where an entity can consume and produce simultaneously extemporised in a complete paradigm shift. This requires a detailed knowledge base model at each entity level that can react according to contextual changes.

This paper outlines a generic and layered ontology design for such complex *Prosumer* oriented SG, which enables the autonomous integration and real-time management of distributed and heterogeneous sources. It details the relevant layer to the right granularity with keen insight into distributed co-ordination and semantic heterogeneity. It also presents an inductive based reasoning on such ontology to make it thoroughly elucidative.

Categories and Subject Descriptors

H.4 [**Information Systems Applications**]: Miscellaneous

Keywords

Smart Grid, Prosumers, Ontology design

1. INTRODUCTION

Electrical Grid has evolved surprisingly less over the past 50 years, while the population and electricity demand has grown considerably. The current version of electrical grid suffers from number of problems including, inefficiency, unreliability in demand response, ill-equipped to handle integration of renewable sources and relying on uninformed infrastructure to educate users regarding their usage level at any given time. The term Smart Grid (SG) can be illustrated as according to the description of Energy Independence and Security Act of 2007 [1] ``*Smart Grid refers to the modernization of electricity delivery system that can monitor, protects and automatically optimizes the operations of its interconnected elements.*

[1]http://energy.gov/eere/femp/articles/energy-independence-and-security-act

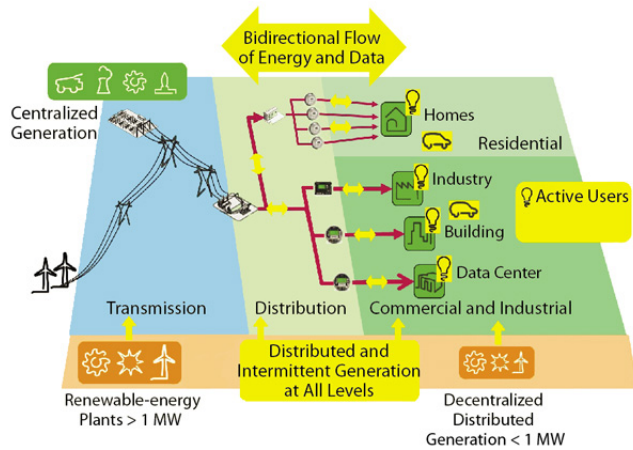

Figure 1: Prosumer Oriented Smart Grid[2]

It starts from central and distribution generation, through the organization of system, to the end user's (residential, industrial) automation, electricity storage and household devices". Hence, SG is characterized by distributed flow of energy and information to create an intelligent energy delivery system.

This paradigm shift introduces an intriguing concept of *Prosumers*, an entity that blurs the distinction between the consumer and producer as depicted in Figure 1. Such docile combination allows a bi-directional flow of energy and information, where even the consumers (residential, industrial) can produce and trade unused energy. The centralized grid in-charge of distribution can utilize this reverse flow of energy by herding it towards power critical users. Moreover, geographical localized Prosumers can conform a Smart micro grid to share over-harvested energy. This accrues systematic reliability of SG and decreases the cost, while eschewing CO_2 emissions by employing renewable energy sources at Prosumer premises. This cohesion of efficiency by such system can be regarded as passive manoeuvre by engaging a consistent consumption model, while Prosumer oriented SG triggers an active plan by manifestation of Demand Response (DR), thus allowing the production of energy on the basis of meticulous demand, which in return mitigate the energy losses.

Engineering an intelligent Prosumer oriented SG requires obsequious modelling of information acquired from distributed sensors, while considering the realm of both producers and consumers. Although, the main challenge in this case is, how to collect data from

[2]http://www.greenmanufacturer.net/article/machinery-and-equipment/demand-response-the-power-program-that-pays-you-back

each energy source at individual level, considering the presence of various techniques and data models. The two indigenous approaches used to acquire such data are *Direct Sensing* and *Single Point Sensing* [5]. *Direct Sensing* employs each device with a distant sensor, while *Single Point Sensing*, uses one sensor to disambiguate all the appliances with total voltage measurement as events [6]. Since Prosumer oriented concept of SG involves in profound role change of system-wide stakeholders (Consumers, Producers, Prosumers), there is a compelling need of handling, storing and extracting knowledge out of data received from heterogeneous sources. Semantic web offers such functionality by allowing Smart Grid to imbue with intelligence, logical and domain specific reasoning and meticulous mapping between entities. Thus, a generic and layered ontology plays a vital role in embedding efficient knowledge reasoning and management of bi-directional flow of information.
The rest of the paper is distributed into two sections. Section 2 discusses the design and requirements for generic and layered ontology and Section 3 examines the rule-based inductive reasoning on domain ontology.

2. ONTOLOGY MODELLING

An optimized ontology is characterized by encapsulating entire domain concepts to the right granularity. Since modern systems evolve continuously with time and SG is still far from its standardized model, thus it faces number of issues, such as complexity of network, large number of entities, diversity in architecture and highly flexible requirements. This solicits a generic knowledge base design, where all the participants of the system are modelled and linked to the right granularity. The idea of dynamic ontology integration [8] may be applicable to such context, where different versioning techniques are used to focus the impact of changes on logical consistency of ontology. Although, in the context of complex Smart Grid, where current and historical information are both expedient and system comprised of large number of heterogeneous and distributed sources, such techniques won't suffice to solve semantic heterogeneity [9]. For instance a media player could be a simple stereo system or a professional sound system. This however, enlightens the pressing need of a generic and layered ontology design, where these diverse entities should be mapped according to their context. The acceptable requirements of such system are two folded. Firstly, the knowledge base data model should encapsulate all the information at right granularity (generality). Secondly, it should entertain any evolved context without disturbing the overall structure of knowledge base (layered). Therefore, it requires an ontology design that can adapt according to a new concept, such as if a new device is added at consumer premises that is not yet defined in domain ontology. Furthermore, the system should employ a layered ontology, where classified concepts could be modified without affecting the whole model. For instance, if a new type of power generator is added to the system, it should only require the addition of new concept in right class without modifying any link in domain ontology. The integration of Prosumers to such complex system, where individual entities co-operate with each other according to their goals and geographical location, begets it more challenging to annotate available data with well-defined relationships that provide the accurate context of their use.

2.1 Use Cases

In order to consolidate and excite the idea of modelling multi-domain and flexible ontology, we present some use cases as following. This is not an exhaustive list, but a cross-section of interesting use cases.

Ad-hoc Based :

- A-UC 1: Find a residential sector with highest power consumption rates and advise the system regarding the type and number of new storage or renewable sources that should be added in order to satisfy its demands and reduce energy cost (micro grid composition).
- A-UC 2: Determine the most economical, reliable and environmental friendly energy producer in a certain city. What kind of energy is produced by such source and compare the change in their production capacity with corresponding weather conditions?
- A-UC 3: Determine the number of consumers connected to a specific producer and list their infrastructure type, energy classes and total revenue generated since last 2 months.
- A-UC 4: Compare all the power sources used by a certain premises for the last 6 months as according to their reliability, costs and environmental effects.

Advice Based :

- AB-UC 1: What is the total power consumption for appliances with power rating greater than 1000 Watt in a certain premises and describe their usage patterns for the last month at the temperature range of 27-35 C. Additionally, advise about better scheduling to reduce the cost of electricity?
- AB-UC 2: List feasible dates and times, which would be cost effective to operate a washing machine in certain premises by comparing past consumption patterns.

Event Based :

- E-UC 1: In an event of power failure or shortage from a certain generation source, switch to back-up energy storage or other available power sources.
- E-UC 2: If the generator power source rating is 3KWatt for last 2 hours during peak time with price ``P1" and only low voltage (10-100Watt) appliances are operational at current time, then check the status of attached power storage unit, if it's more than 70% charged then shift the load from the main power source to storage source.

The following section illustrates our ontology design for Prosumer oriented SG. Our ontology[3] is divided into eight conspicuous layers as depicted in Figure 2.

2.2 Infrastructure Type

The power consumption patterns directly correlate with infrastructure's operational type, time and geographical location, which evocates the requirement of such classifications. For instance a residential house will consume more energy at night or weekends, while consumption demand of an office varies according to working hours. Additionally, these premises based classification can identify each entity in the system by using the address property and attributes it as normal or power critical, e.g. a hospital requires more reliable energy source as compare to residential property. These distributions are influenced by UK property classifications[4] and are as following.

Commercial Premises Entities in this class consist of commercial premises, such as retailing shops, food restaurants, cinemas etc. with varying operating times depending on the type.

[3] `http://data-satin.telecom-st-etienne.fr/ontologies/smartgrids/smartgrid2.ttl`
[4] http://www.legislation.gov.uk/uksi/1987/ 764/article/3/made

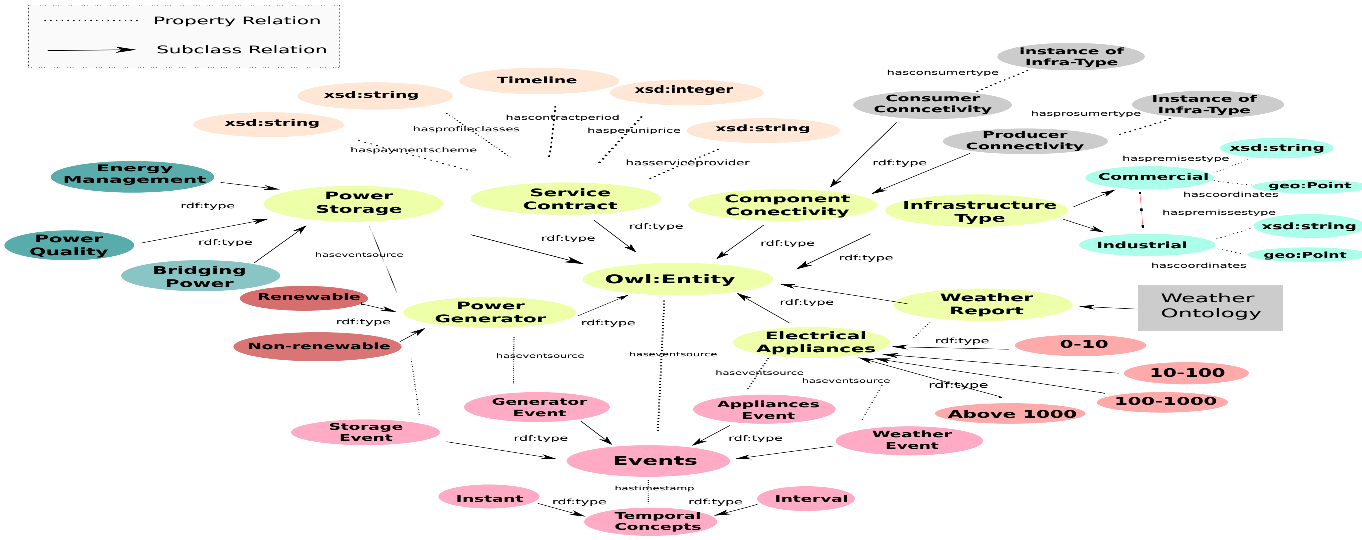

Figure 2: Prosumer-oriented SG Ontology Design

Business Related Premises This class constitutes various business related entities. These premises usually operate during office times, thus it would permit to postulate their consumption behaviours and better scheduling algorithms.

Residential Premises This class deals with residential premises and plays a vital role to determine the overall consumption of the SG, as it constitutes of nearly quarter of total energy consumption, additionally, residential consumption patterns are agitated before and after office hours.

Non-residential Institutions This class consists of non-residential institutes such as hospitals, schools, libraries etc. These premises accord as power critical ones and require a higher priority.

Industrial Premises This class defines the industrial infrastructure, where industries demand an uninterrupted and reliable power source, thus modelling such entity portrays the consumption pattern of power critical sources and aids in assigning power sources.

The importance of such distribution can be concluded from A-UC 1. Hence, in order to accurately advise a consumer reading storage choice, infrastructure type should be taken into consideration because residential premises can't afford an industrial type storage unit and its preferred choice should have fast charging and discharging response. Furthermore, micro grid composition is more feasible in residential sector as compared to industrial one. Such information comfort the composition of smart micro grid, better scheduling to reduce consumption costs and prioritise the power distribution accordingly.

2.3 Electrical Appliances

The efficient management of heterogeneous electrical appliances residing in different entities require automatic collection of data from power consumers. Direct sensing promises an exact consumption and temporal data, while single point sensing reasoned for a more practical solution by using a single sensor to disambiguate different appliances. This demands a generic data structure that can accommodate both direct and single point sensing. Additionally, there could be numerous novel devices tuning in to the system that would require a flexible data structure. This leads us to classify these devices in a two layered architecture, where first layer divides the consumer devices according to their power ratings, while second layer classifies them according to their exact type (mining appropriate IEC CIM [5] defined devices). This enables the ontology to grasp the dynamic nature of SG.

The gravity of this distribution can be judged from AB-UC 1. Where appliances with higher or mid-level power consumption requires better scheduling and most of these appliances (washing machines, water heaters) demonstrate repeatable switching pattern along certain time periods, while appliances with lower levels permit to continuous consumption pattern. Consequently, these classifications will aid in implementing inductive inference to distribute appliances according to their operational/consumption patterns. This assortment of appliances are comprised of 0-10 Watts of basic household and office appliance with lower priority of scheduling, 10-100 Watts of mid range appliances and over 1000 Watts of higher powered and priority devices.

2.4 Electrical Generation System

Smart Grid encompasses a vast number of diversified, distributed and variable energy sources, which endeavour to model these energy sources within the domain ontology. Additionally, the comeliness of Smart Grid resides with its flexible architecture that allows the integration of renewable energy sources, while mitigating the climate effects. This very point rested a compelling case to classify each power source not only according to its operational type but also regarding the type of produced energy. This classification will provide an omniscient view of the system, while offering valuable information to the end users. Our ontology captures these classifications as following.

Non-Renewable Energy Non-renewable energy sources encompass all kinds of fossil fuel and its classification is based on their carbon footprint, while considering both direct - arising during operational power plant and indirect - arising during the non-operational phases of production life cycle (cradle-to-grave).

Renewable Energy Renewable energy exists perpetually, inexhaustible and more importantly a clean alternative to non-renewable sources. Although it is regarded as green energy, but Its reliance on weather conditions demands the classification of renewable sources according to their operational types. For example wind, solar.

[5] http://www.iec.ch/smartgrid/standards/

The classification of such power sources can be regarded as an important part of the ontology and its absence would impede efficient management of energy sources. A-UC 2 enlightens its importance. For instance, a competent energy source should be reliable and environmental friendly, where fossil fuel produced energy is regarded as reliable with huge CO_2 footprint, while renewable energy sources are much more cleaner but its reliability varies according to geographical locations and weather conditions.

2.5 Power Storage System

Power Storage systems provide three crucial services, firstly it depletes the electricity cost by storing it during the off-peak times, secondly, it improves the reliability of the system in case of power network failure. And finally to maintain and improve the power quality, frequency and voltage. Additionally, renewable energy sources can maximise their production efficiency when paired with an energy storage system. These storage systems are classified according to type, produced power, charge-and-discharge efficiency, cost per KHW [3]. Such attributes can guide the consumer regarding economics and reliability of a storage system. There are two principle criteria to classify various storage systems: functional and forms, as the context of SG demands more of functional attributes, consequently modelling such behaviours at knowledge level resonates well with load balancing and scheduling of power storage systems.

Energy Management These types of storage solutions are usually equipped with large-scale entities drawing power up to 100MW. Hence, they can be regarded as sole power generator sources and most of the industrial based renewable energy sources are connected to such storage units. This class of devices is attributed with higher charging and discharging time periods.

Power Quality Storage devices of this class are utilized for power quality, such as instantaneous voltage drop, flicker mitigation and short duration uninterrupted power supply. They are equipped at relatively lower power consumers (residential) and have lower charging and discharging time periods.

Bridging Power These are more responsive type of storage devices with relatively fast response and long discharging time. These are usually installed at residential renewable sources with power rating of about (100KW-10MW).

This distribution recommends an efficient scheduling of power generator and storage sources and A-UC 1 is influenced by the right characterisation of these storage sources. As the right functional type of these sources determines if a premise is using it merely as a energy source or as a dis-patchable generation source to accord for power shortage and to mitigate frequency problems. Furthermore, by determining weather conditions, infrastructure type and required characteristic of an entity, system can predict a better choice of storage unit. This constitute a strong case for behavioural distribution of storage units rather than just according to their storage capacity.

2.6 Weather Report

Weather and temperature are important drivers of electricity consumption and production patterns and meticulous forecast of energy production relies on accurate measurement and modelling of weather data. AB-UC 1 and A-UC 2 straighten out the importance of such information. As change in weather conditions leads to the use of high power appliances (air-con in summer, heater in winter) and in order to avoid power shortage during these periods, the system should build forecasting models for consumption patterns and schedule these sources in acceptable and efficient manner. Furthermore, the production of alternate or renewable energy directly relates to fickle weather conditions and reliability of these sources can be predicted by modelling weather related information. There are various ontologies available for modelling such functionalities, such as NNEW [6] and SSN [7].

2.7 Events

Smart Grid deals with real-time monitoring and management of interconnected entities, this emanates a system equipped with Complex Event Processing (CEP) [1] that is able to detect occurrence of specified patterns of events and respond accordingly. Thus, fabricating events becomes a legitimate objective of ontology, where it must be capable of accounting for spatial relation both synchronically and diachronically. Such functionality can be embedded to ontology by classifying each event type, temporal annotation and their relationship with domain entities. This distinction is based on the fact that an event may involve with number of processes. E.g. a change in the consumption power of an entity might involve in turning a washing machine off or turning on a hover. This requires an exact relationship of an event with corresponding sub-entity. Our ontology segregates events into following four types.

Electrical Appliance Events These events are coined to the electrical appliance and trigger the change in the consumption pattern, which in result prompt the process of load scheduling or change in demand response.

Weather Event These events capture the context of drastic change in weather, as power consumption and production is directly related to weather condition, thus mining those events lay down the ground for predicting consumption and production behaviours.

Storage Events The anticipated production capability of a storage system is highly dependent on its temporal aspects, such as, performance of a storage unit is directly proportional to its charging and discharging time and complying with such events aid in articulating the reliability of certain premises.

Generator Events These events deal with the power production capabilities of producers. For instance, if there is a change in the production capabilities or failure of a generator.

Consequently, the notion of Prosumers consolidated with renewable energy sources portray a more complex glimpse of the system as depicted in E-UC 1 and E-UC 2, where with frequent negotiations between available producers crave to capture the current relationship between consumers and producers. Furthermore, in order to predict the reliability of such production facility the temporal events linked to the corresponding sources must be added to the domain ontology.

2.8 Service Contracts Ontology

Service contracts or agreements are legally enforceable promise or undertaking along-with associated conditions. In case of Prosumers, these contracts will be between two parties, one who produced electricity (seller) and one who will like to consume electricity (buyer). Contractual information is quite cogent for communication between producer and consumer domains as in a competitive market; this information will directly cajole the decision and preference of both parties. Modelling such information will enable the consumer to choose a service provider entailing better economical deals and will guide producer to offer lucrative deals in order to attract maximum number of customers. The various properties associated with this class of ontology includes, the name of service provider, Start Date/End Date of contract, Profile Classes[8] of con-

[6] https://wiki.ucar.edu/display/NNEWD/
[7] http://www.w3.org/2005/Incubator/ssn/ssnx/weather-station/
[8] http://www2.ademe.fr

nected consumer, type of payment scheme for the connection, early contract termination charges and per unit price of electricity.
This part of ontology draws a comprehensive attention towards competitive energy market. Consequently, with the integration of Prosumers, each entity will prefer a flexible energy package and such properties in domain ontology not only assist consumer to determine the right connectivity type but also advocate a producer to predict the approximate energy demand of a consumer according to described consumer profiles and thus, calculate total revenue generated from such consumers as depicted in A-UC 3. For example, an energy provider can classify a city according to consumption classes of customers while calculating revenue in each sector and prioritise or increase the production facilities to areas with higher revenues or predicted energy consumption.

2.9 Component Connectivity

The movement towards renewable energy resources and the apparent awareness of energy consumption lead to new challenges in the distribution grid and energy production. This distributed and decentralized power generation leads to the concept of smart microgrid, where a group of loads and energy sources are aggregated together to appear as a single asset in a localized way. This formation requires the correct location of connected sources, thus this part of the ontology focused on defining the exact connectivity relationships between producers and consumers. Furthermore, these properties can also be used to determine the efficiency and expected load of consumer entities. An entity coined as a power source classifies consumers according to their total consumed power and an entity under consumption's tutelage record the type of energy produced by the power source and total power consumed from such sources, while inheriting all the types discussed in Power generation and Storage system. Component connectivity advocates much of the moral motivations of a consumer. Since consumer decides its energy source according to its reliability and produced carbon footprint. As depicted in A-UC 4, the connectivity information of these distributed sources and sinks is quite essential to compare the overall performance, such information assist in reasoning the user's preferred energy type, as environmental aware consumers will prefer alternate energy, while industrial users will prefer more reliable energy source like nuclear or fossil fuel.

3. RULES BASED INDUCTIVE INFERENCE

Inductive inference involves in looking various patterns/trends and classifying them according to their properties. Its judgement process is influenced by heuristics and rules that tap into associative information about context and similarity. This, however is more non-monotonic in nature, where the conclusion of premises are drawn much due to the presence or absence of them and are bound to change, when more knowledge is acquired and previously drawn conclusion may have nullified, as the rules of inference that led to them may no longer be active. Such inference process consist of two main approaches, where the first one merely draws statistical conclusion based on historical data, while the later deals with predicting future values by utilising probabilistic models, such as Bayesian inference [4]. Let ``$X$'' is a set of observed characteristics from data and ``Y'' is a set of predicted outcomes then, $\Omega = (X \otimes Y)^{\infty}$, where Ω is a set of concluded states and can be narrow downed to the right granularity by employing Bayesian model [4]. In the context of SG, where efficient scheduling and management of energy sources makes quite the case, these inferred incremental part of ontology drives the effective reasoning and analytical job. The three main types of these incremental ontologies

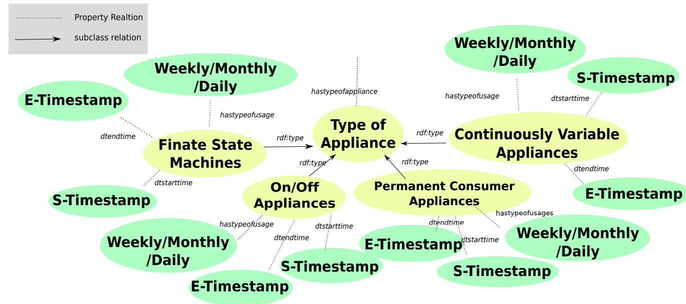

Figure 3: Inductive Ontology for Appliance Consumption Patterns

that ex-cogitate from inductive inference are as following.

3.1 Appliance Consumption Patterns

The efficient management of electricity requires classification of consumer appliances according to their operational patterns and provide the required flexibility in controlling electricity costs. Such methods of controlling electricity consumption are directly related to demand response, which relies on varying price of electricity to reduce peak demand. For instance, a washing machine electricity consumption pattern is usually weekly, hence it can be scheduled to operate at night during weekdays (AB-UC 2). Furthermore, consumer entity could entail the production attribute, thus it can sell its produced power according to the consumption patterns of its appliance. Consumer appliance can be classified according to assigned rules into three main types, depending on their consumption patterns [10] [6], as depicted in Figure 4.

Finite State Machines or Multi State Devices This category includes the devices that have repeatable switching patterns. Thus, the switching cycle could be repeated daily, weekly or monthly. Examples are washing machines, dryers and lawn mowers.

On/Off Devices This includes the most household devices that are turned on and off in frequent manner, such as toaster, light bulb, water pumps etc.

Permanent Consumer Appliances This category inclu-des the appliances that remain operative for all the time (24x7). Example includes hard-wired smoking alarms and some power supplies.

Continuously Variable Consumer Devices This category includes the devices with variable states and draw power randomly without any specific pattern. E.g. Power tools, dimmer lights.

These classifications follow the non-monotonic principle and they revised itself with change in newly acquired data. Furthermore, as according to AB-UC 1 and AB-UC 2, extracting meaningful appliance patterns can not only assist the users with understanding their behaviours but also to make judgement in relation to better scheduling of appliances during peak hours in order to reduce the overall cost of electricity.

3.2 Alternate Energy Production Patterns

Energy produced by almost all renewable energy technologies is wholly dependent on the weather. Wind and wave power depend on the speed, direction and duration of the wind. Solar power, whether photovoltaic or thermal, depends on the intensity and duration of solar irradiation. Consequently, weather and climate is a common denominator for all of these increasingly important sources of renewable energy. To determine the expected energy yield of a renewable power source, inductive reasoning can match the past patterns (production and weather) and predict the future production accordingly. Embedding this information in the ontology will enable the consumer to predict the reliability of the energy source and also helps in distributing load of consumer appliances. IBM's [9] new advanced power and weather modelling technology showcases the importance of such information.

3.3 Producer's Performance Patterns

The performance of an energy producer can be judged from its efficiency, economical operations and impact on the environment. SG not only promises a more efficient and reliable system but also emphasis on the reduction of greenhouse gases (GHG), which emphasis on reliable audit of energy producer. Hence, each consumer can infer the reliability of its producer by applying inductive reasoning on its past patterns. As performance critical entities, for instance hospitals and industries will prefer a more reliable source. Furthermore, in order to accurately compare carbon footprints of these different technologies, the total CO_2 emitted through the production cycle must be calculated. This measurement will influence the consumers to priorities the choice on the bases of reliability and/or environment friendly consumers. The carbon footprint of each producer entity can be calculated by comparing the type of the power plant and produced power.

4. RELATED WORK

There are various industrial standards that co-exist for SG model, e.g. IEC CIM and NEMA[10], but these standards are not diversified, and detailed enough to embed into Prosumer oriented SG. Although appliance description as mentioned in IEC CIM (as discussed in Section 2.3) is quite interesting and our model extracts and extends these useful concepts and exploits them for low-level appliance description.

Semantic based modelling discussed in [7] offers certain design guidelines to effectively integrate smart grid to the household appliance. It emphasis on heterogeneous data acquisition and how it could be used to provide value added services to users. But, with the integration of distributed alternate energy resources and Prosumers, the model requires to cater this useful information to harness the effective energy exchange between various entities. [11] describes an interesting ontology for mapping household devices by integrated various available ontologies. It also outlines an interesting event processing architecture considering the context of Smart Grid. The main drawbacks that can be inferred from such techniques are its reliance on direct sensing and failure to capture real world scenarios. Its ontology is quite detailed in nature by integrating IEC CIM concepts, where such information cannot be extracted from each and every household. Furthermore, nothing sustainable has been discussed regarding the compatibility of these integrated ontologies and presented ontology is still in conceptual stage without any implemented version. [2] describes a semantically rich energy management system, where ontologies are used to represent each customer in a relevant domain, focusing on its energy usage and environment. These facts are then reasoned to infer the relevant tips for customers. This work doesn't detail any information regarding the acquisition of data and the conceptual ontology and reasoning is performed on a static set of triple store rather processing any real time events. However, A-box and T-box assertion from customer data mimics the usefulness of extending ontology in the context of energy management systems. In a whole, state of art ontologies for Smart Grid are unable to capture the real world scenarios or various heterogeneous domains (generation, storage) this leads to an abstract ontologies that doesn't cater each domain level in detail.

[9] http://www.ibm.com/press/us/en/pressrelease/41310.wss

[10] http://www.nema.org/pages/default.aspx

5. CONCLUSION AND FUTURE WORK

In this paper we present a multi-dimensional and generic ontology model equipped with inductive based reasoning and complex event processing, by attributing each domain of interest with relevant relations. These relations and requirements, as depicted in our ontology are ratified through our use cases, while considering the context of Prosumer oriented SG. Our future endeavours involve in integration of proposed ontology with SEAS project [11] and regress testing with various SG based simulators. Furthermore, we intend to develop an open source engine for complex event processing using distributed multi-agents paradigm in the context of Prosumer oriented SG.

6. REFERENCES

[1] D. Anicic, S. Rudolph, P. Fodor, and N. Stojanovic. Etalis: Rule-based reasoning in event processing. *Semantic Web: Interoperability, Usability, Applicability*, 2011.

[2] P. Chaussecourte, B. Glimm, I. Horrocks, B. Motik, and L. Pierre. The energy management adviser at edf. In H. Alani, L. Kagal, and A. Fokoue, editors, *The Semantic Web-ISWC 2013*, volume 8219 of *LNCS*, pages 49--64.

[3] H. Chen, T. N. Cong, W. Yang, C. Tan, Y. Li, and Y. Ding. Progress in electrical energy storage system: A critical review. *Progress in Natural Science*, Mar. 2009.

[4] M. Feldkircher. Forecast combination and bayesian model averaging - a prior sensitivity analysis. Working Papers in Economics and Finance 2010-14, Sept.

[5] J. Froehlich, E. Larson, S. Gupta, G. Cohn, M. Reynolds, and S. Patel. Disaggregated end-use energy sensing for the smart grid. *Pervasive Computing, IEEE*, 10(1):28--39, 2011.

[6] G. Hart. Nonintrusive appliance load monitoring. pages 1870--1891. IEEE, 1992.

[7] A. Monacchi, D. Egarter, and W. Elmenreich. Integrating households into the smart grid. In *Modeling and Simulation of Cyber-Physical Energy Systems (MSCPES), 2013*.

[8] P. Pittet, C. Nicolle, and C. Cruz. Guidelines for a dynamic ontology - integrating tools of evolution and versioning in ontology. *CoRR*, abs/1208.1750, 2012.

[9] M. Uschold and M. Grüninger. Ontologies and semantics for seamless connectivity. *SIGMOD Record*, 33(4):58--64, 2004.

[10] M. Zeifman and K. Roth. Nonintrusive appliance load monitoring: Review and outlook. *Consumer Electronics, IEEE Transactions on*, 57(1):76--84, 2011.

[11] Q. Zhou, S. Natarajan, Y. Simmhan, and V. Prasanna. Semantic information modeling for emerging applications in smart grid. In *Proceedings of the 2012 Ninth International Conference on Information Technology - New Generations*, ITNG '12, pages 775--782. IEEE Computer Society.

[11] https://itea3.org/project/seas.html