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Customer Centricity in the Smart Grid Model

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Abstract

The demand for sustainable energy is caused by the rapid influx of the rising number of urban cities worldwide. In 2014, roughly 54 percent of the world's populations live in urban areas, and the numbers are expected to go up to 70 percent by 2050. A smart grid is considered as one energy approach to address the increasing demand for sustainable energy. Currently, the U.S. is accelerating the smart grid movement and efforts to modernize the electric grid. The authors will provide an overview of the electricity industry evolution and the emergence of smart grid. Most researchers tend to focus on the physical infrastructure and information layer of the smart grid. However, the most important aspect, which is the social aspect that fuels the advancement of any technology, is often neglected or forgotten. Customer interaction with the utility service provider is arguably one of the key factors of a successful smart grid. But, customers are considered as end users and are often the last in the communication chain to find out about changes in the energy service system, including the ongoing implementation of the smart grid. This paper presents a case study on the State of New York's latest ambitious efforts in reforming the energy vision and their strategies to be proactive in actively engaging customers in the ongoing development of the smart grid. The authors explore the customer-centricity in a smart grid and their interactions using a formalized object oriented modeling approach to reason about the problem, understand the complexity of the evolving energy service system, and communicate about the smart grid with others[1].

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Keywords: smart grid; sustainable energy; customer; utility service provider; electricity; SysML; socio-technical system

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1. Introduction

The emergence of distributed energy generation operating within a microgrid began when Thomas Edison started his small Pearl Station, New York City, NY power station in 1882[2]. While the national grid has had preeminence over the past 100 years, microgrids have made significant progress and are continuing to evolve into smart grids. The modernization of the U.S. electric system is underway to provide cleaner, smart power systems, including the utilization of renewable energies in order to meet the current demand and future energy needs of the U.S.[3] Renewable energy systems are one of the grand challenges of the 21st century, as stated by the National Academy of Engineering (NAE) leading to numerous research efforts by the government, industry, and research universities[4]. The U.S. Department of Energy (DOE) has identified microgrids as a major component of the smart grid to improve the efficiency and reliability of the energy system[5].

Based on the data from the U.S. Energy Information Administration (EIA), Fig. 1 represents the energy production in the electric power sector over the last 60 years[6]. Since 2008, there has been a decline in the use of coal and petroleum in electricity generation. Meanwhile, the electricity generation from natural gas and renewable energy sources improved. As the demand for energy continues to rise, it is important to address this growth using renewable energy coupled with the conventional non-renewable energy sources.

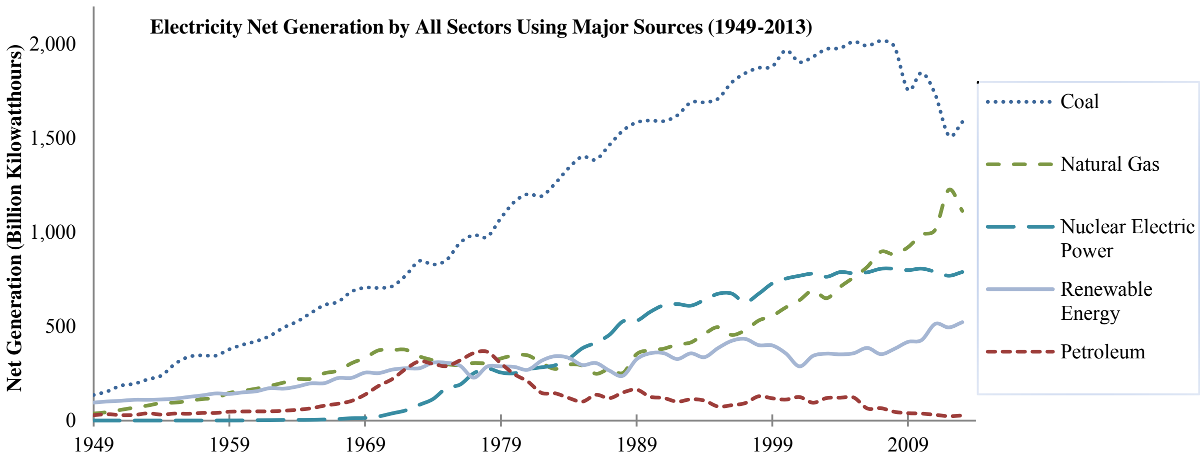

Fig. 1. U.S. electric power net generation by major sources from 1949 – 2013[6]

This research paper demonstrates the importance of smart grid and studies the role of customers as a major stakeholder in the smart grid evolution by addressing the following research questions:

1. What is the current progress in the evolution of smart grid in the U.S.?
2. How can the customer-centric strategies developed by the State of New York help them to be successful in their current development of a smart grid?

In order to address the research questions, section two of this paper provides a brief history of electricity and the growing customer demand of electricity. The following section presents the emergence of advanced technologies and the current progress in the evolution of the smart grid. After that, the authors present a case study of the State of New York and in particular, Con Edison's innovative approach in engaging customers to generate sustainable energy in their ongoing improvement of the smart grid. Finally, the authors considered the relationships and interactions between the customers, regulators, and the utility service provider to understand the prominence of customer centricity in the complex energy service system.

2. Evolution of Electricity

It is important to explore the history of the electricity industry as the power generation and consumption changed over the years. It could be argued that electricity has always been around. It is the energy stored in all different forms and shapes, where it appears. The ancient world witnessed electrical energy in the form of lightning though they did not understand the cause and did not know what electricity was, but observed the phenomena of the resulting power of Mother Earth's energy. In the 17th century, Benjamin Franklin (1704-1790), was the first to introduce his observations on the two basic elements generating electricity, positive and negative charges. The term electricity was not introduced yet. This phenomenon was called the static electric charges[7]. Soon after, the professor of anatomy and surgery, Luigi Galvani, who was interested in the field recognized then as medical electricity, specifically electrophysiology, proposed the theory of animal electricity. His third and last work in 1797, one year before his death, was published defending his theory of animal electricity from its controversy. This led his opposer, Volta Alessandro, to research more and build the first battery to contradict his associate's theory on the cause of muscular contraction and electric fluid.[8]

Theoretical understanding of electricity have been very limited and evolved very slowly. The 18th and 19th centuries represented very slow growth, very similar to the technology adoption "S" curve. Initially the electric power grid didn't come into existence until the 19th to the beginning of the 20th century[9]. The electric power applications were limited until Thomas Edison's invention of the light bulb in the 1870s. This initial application of electricity used publicly by people leading cities to form public utilities[10]. In the early 20th century, the development of electricity applications expanded the customer base use of electricity for cooling and heating. The application of electricity further evolved with the advancement of communication, and transportation. As a result, the demands of electricity by all sectors have pushed public utilities to expand further[11]. Fig. 2 shows the retail sales growth of electricity in the residential, commercial, and industrial end-use sectors since 1949 to 2013. The power industry currently has total sales of 37,996 million dollars of revenue[12]. The highest revenue comes from the largest customer base, the residential customer, representing 46.32 percent of the total revenue from all sectors. The commercial customer comes next with 36.87 percent and the industrial customer represents only 16.63 percent[12].

Based on Fig. 2, the number of customers continues to increase and the utility service providers are seeking other electricity generation sources to accommodate the growing demand of electricity. Alternate means of producing electricity sources is evolving due to economic and environmental motivations[13]. Some customers are motivated to invest and install renewable energy systems to generate their own electricity. The public utilities are no longer the only electricity producers and providers. This course of the electricity generation and distribution is changing based on the needs of the customers, which should result in more efficient, affordable and reliable energy system.

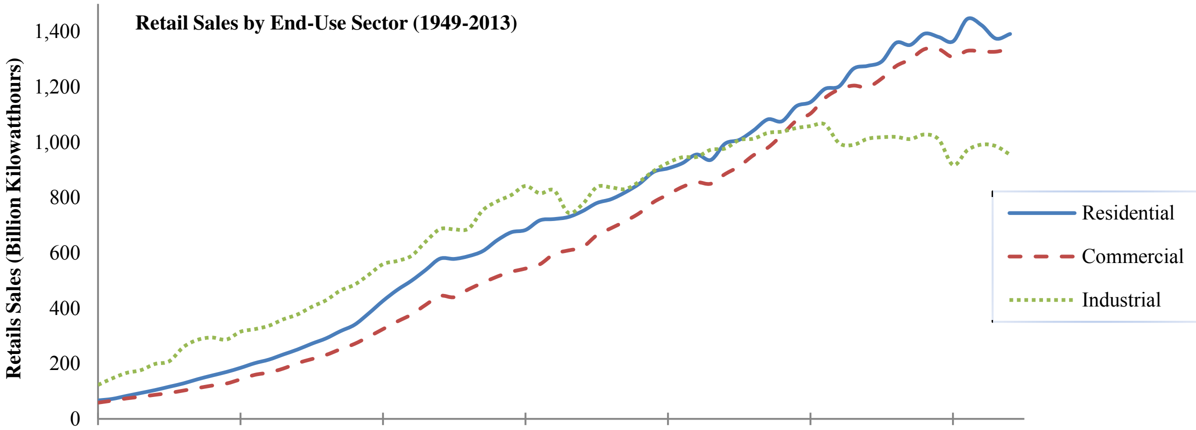

Fig. 2. Total retail sales of electricity by sector from 1949-2013[6]

The electric power grid has evolved from limited servicing of a particular area of customers into a large centralized network servicing multiple topographical areas. Now, there are 5,800 central power plants stations in the U.S.[14]. Based on the data obtained from the U.S. EIA, the Lawrence Livermore National Laboratory (LLNL) and the U.S. DOE depicted the estimated U.S. energy use in 2013 in various sectors from all energy sources in Fig. 3. According to the LLNL[15], the rejected energy (59.0 quads) refers to the energy that is not consumed or energy loss. The electricity generation sector (38.2 quads) accounts for majority of the energy use. The lack of efficiency in the electricity generation technology is most likely the main cause of the rejected energy[15]. The transportation sector has an estimated energy use of 27 quads, but most of it is rejected (21.3 quads), and only 5.66 quads are used in the energy services. The 38.4 quads of energy services refer to the energy consumed in the residential, commercial, industrial, and transportation sectors. The comparison of the rejected energy and the energy services shows the lack of energy efficiency in each sector where 60.57 percent of the total U.S. generated energy is lost[15].

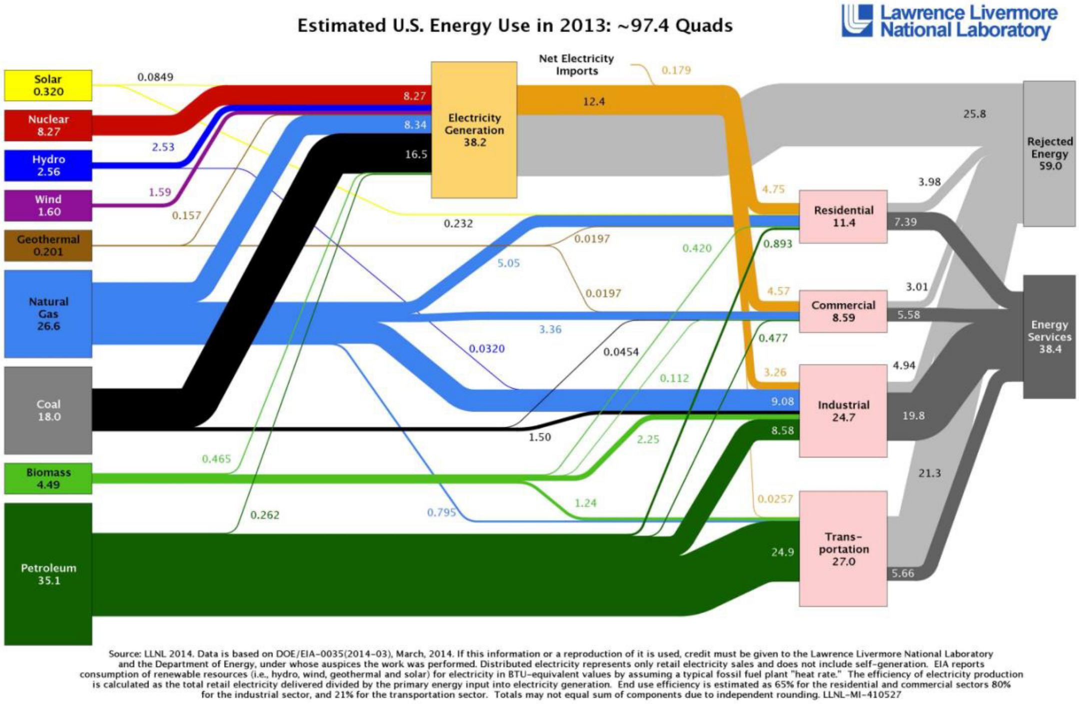

Fig. 3. Estimated U.S. Energy Consumption based on Energy Source and Sector (Quadrillion Btu) in 2013[15]

3. Smart Grid

According to the IEEE Standards Association[16], the smart grid is the integration of power, communications, and information technology for an improved electric power infrastructure serving loads while providing for an ongoing evolution of end-use applications. The smart grid concept is not only a large physical network but a revolutionary trend of improving the existing power grid and optimizing the power grid by the smart coupling between the information and communication technology (ICT) and the integration of renewable energy. Adam and Wintersteller[17] expressed that the smart grid technology would be beneficial for energy optimization through integrated intermittent renewable sources of energy, and the customers involvement through smart metering. Unlike the unidirectional nature of the existing electric grid, the smart grid allows bi-directional communication between customers and the utility service providers through the two-way electricity and information flow. Through smart metering, the utility service provider and their customers can monitor and control real-time information on the energy generation and consumption.

Farhangi[18] defines the smart grid as "a collection of all technologies, concepts, topologies and approaches that allows the traditional hierarchies of generation, transmission, and distribution with an end-to-end, intelligent, and fully integrated environment where all the stakeholders can connect intermittently for an efficient exchange of data, services and transactions". The interactive, dynamic smart grid system continues to evolve with the advancement of smart grid technologies and research. The Energy Independence and Security Act of 2007[19] assigned the primary role of developing an interoperability standards framework for smart grid devices and systems to the National Institute of Standards and Technology (NIST). As a result, the latest NIST framework and roadmap for smart grid interoperability standards, Release 3.0[20] is used as a standard guideline in this research paper. The NIST smart grid conceptual model is comprised of seven domains as shown in Fig. 4. To describe the smart grid architecture and accomplish interoperability between all domains, NIST adopted the Smart Grid Architecture Methodology that has an enterprise-wide and service-oriented approach[20].

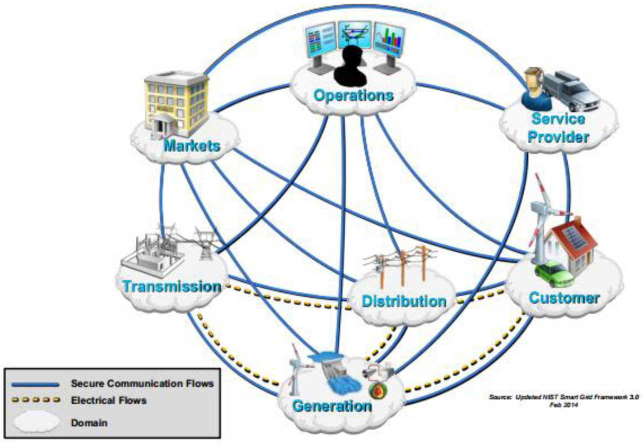

Fig. 4. NIST Smart grid conceptual model[20]

Fig. 5 shows the NIST customer domain in the smart grid model, and appears to be a decomposition of the customer domain in Fig. 4. As part of the recommendations provided by the Federal Energy Regulatory Commission (FERC), NIST highlighted the prioritization of the nine main functionalities of the smart grid. They list the main priorities of the smart grid as the demand response and customer energy efficiency. These functionalities are vital to provide the continuous support for utilities to incentivize customers to change their energy usage behavior and educate customers about energy efficiency[20].

Fig. 5. NIST Customer domain of the smart grid model[20]

4. Case Study of the State of New York

As one of the major financial centers in the world and a top tourist destination that draws in over 45 million visitors annually, New York's population continues to grow along with their energy usage. In the wake of severe and catastrophic events such as Superstorm Sandy and Hurricane Irene, New York Governor Cuomo summoned the NYS 2100 Commission to identify and evaluate the weak points in the state's critical infrastructure systems, and also to provide recommendations to address its challenges[21]. The NYS 2100 Commission reported that the energy infrastructure is one of the main areas that need to be strengthened. Superstorm Sandy caused the State of New York billions of dollars in damages and economic losses[22]. As a result, the State of New York is working progressively to increase the resiliency as early preparation for future catastrophic events to improve the quality of life of individuals. The State of New York's energy system is chosen as a case study in this paper because of its new and ambitious approach to modernize the overall energy sector from the generation to the distribution of energy, as well as increasing the customers' awareness about energy efficiency. New York's pragmatic efforts are being watched closely and examined by other states. This paper highlights some of the new initiatives to accelerate the smart grid movement in the State of New York.

In April 2014, Governor Cuomo introduced New York Reforming the Energy Vision (NY REV) initiative to expedite the state's energy service system towards a market-based, decentralized structure[23]. The NY REV framework serves as a way to improve incentives and discard disincentives in the current energy sector. The NY REV includes incentivizing the integration of renewable energy, demand response, and distributed generation for customers. The goal of NY REV is to create a more efficient, greener, and more reliable electric grid. The New York Independent System Operator (NYISO) and New York utility service providers are working together to implement new technologies to incorporate energy management tools to optimize the electric grid. One of the most ambitious and interesting approaches from the NY REV is the NY Prize competition to develop a minimum of ten energy community grids and microgrids in 2014[23]. This accelerated approach provides opportunities for innovators and entrepreneurs to compete and contribute innovative solutions to modernize the electric grid in New York.

The New York State Energy Research and Development Authority (NYSERDA) administers large programs based on Governor Cuomo's initiatives such as the NY-Sun, NY Green Bank and Fuel NY. NYSERDA is a public benefit corporation that fosters partnerships to advance and accelerate the innovative solutions in the energy system in the State of New York for a sustainable economy and environment. Since NYSERDA is a public benefit corporation, customers are the main stakeholders and top priority in their mission and vision. The five key programs by NYSERDA are listed as follows[13]:

- Energy efficiency and renewable energy deployment
- Energy technology innovation and business development
- Energy education and workforce development
- Energy and the environment
- Energy data, planning, and policy

The U.S. DOE recognized NYSERDA as being one of the best government research organizations in the U.S. [13] In their active role fostering partnerships between the private and public sectors, NYSERDA has remained customer centric and continues to empower their customers to make wise decisions in clean energy. NYSERDA provides the technical expertise and funding programs aimed at promoting energy efficiency and protecting the environment. This helps New York residential, commercial, and industry customers reduce their energy waste, and decrease their energy bills. They also provide financial assistance in the form of incentives and loans to customers. NYSERDA is one of the catalysts driving the behavior change in creating high impact programs for New York customers.

One of the programs administered by NYSERDA is the NY-Sun initiative which is a partnership between the public and private industries established in 2012 to make solar technologies more efficient and affordable for New York customers. During the first two years of the NY-Sun initiative, 316 megawatts of solar power has been installed or underway, accounting for a reduction of 116,000 tons of greenhouse gas emissions. The 316 megawatts of solar power installations were more than the total solar power that was installed in the past ten years. In 2014, Governor Cuomo made an announcement to invest $1 billion to expand the solar power capacity industry for a sustainable source of clean energy. NYSERDA, Long Island Power Authority (LIPA), Public Service Enterprise Group (PSEG) Long Island, and New York Power Authority (NYPA) are working together to transition from the previous solar programs to increase their efforts to add over three gigawatts of installed solar capacity in the State of New York by 2023[24].

This paper highlights the efforts of one of the utility service providers in the State of New York, Con Edison, which is a subsidiary of Consolidated Edison, Incorporation. Con Edison is known as one of the biggest investor-owned energy companies in the U.S. and is the regulated utility providing electric, gas, and steam services for over three million customers in the State of New York[25]. Con Edison is also a key commercial center that accounts for approximately nine percent of the U.S. Gross Domestic Product. In this growing digital economy, there is an increasing need and dependency on electricity, necessitating for a more reliable and resilient power grid. As in other parts of the U.S., New York's electricity physical infrastructure is aging, and the capital investment required to replace these aging infrastructure is expected to be approximately $30 billion in the next ten years[23].

Typically, utility providers would resort to building another substation to supply the growing demands for energy. However, Con Edison took a novel approach. Instead of spending $1 billion to build another substation, Con Edison is investing in other opportunities to deliver reliable power such as utilizing microgrids, energy storage systems, and energy efficiency programs. Recently, Con Edison teamed up with NYSERDA to administer the new energy demand management incentive called Brooklyn/Queens Demand Management Program. Con Edison plans to invest $200 million in customer-side demand management programs and another $300 million investment to upgrade some substations to reduce 52 megawatts of load from targeted areas by 2018. As part of their customer-side load management program, the Targeted Steam Air Conditioning Incentive Program was launched. All Con Edison steam system customers that are selected will receive incentives to install newer, more efficient steam chillers instead of electric chillers, or rebuild the steam turbines instead of converting to electric driveline[13].

The illustration in Fig. 6 shows Con Edison's smart grid initiative and the constituent systems that are interconnected and critical for an implementation of a successful and sustainable smart grid.

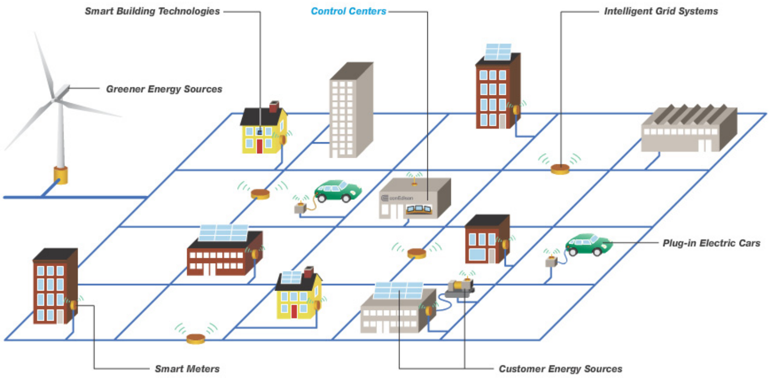

Fig. 6. Con Edison smart grid illustration[25]

In order to better understand the smart grid illustration above, Table 1 lists the constituent systems and its functionalities. To implement the smart grid successfully, the utility provider needs to understand and establish a better customer-utility relationship with open communication and consider the customers as partners in this mission.

Table 1. Constituent systems and corresponding functions in Con Edison's smart grid initiative[25]

System Name	Functionalities
Control Centers	Analyze real-time information in the grid to manage, plan, and forecast the dynamic energy system
Intelligent Grid Systems	Utilize advanced communications technology to locate issues on the grid and repair them in a timely manner to improve reliability
Plug-in Electric Cars	Connect to the grid for overnight charging or whenever the energy demand is low to reduce air pollution and greenhouse emissions
Customer Energy Sources	Generate solar power for personal consumption, and sell back excess energy to the electric utility provider
Smart Meters	Collect data about customers energy usage and monitor the energy supply in real-time for planning and forecasting energy peaks
Greener Energy Sources	Integrate wind, solar, biofuels, and more hydroelectric energy sources into the current electric system to reduce dependencies on fossil fuels
Smart Building Technologies	Invest in energy management systems and use smart appliances with in-home energy monitors that communicate with the smart meter to manage energy usage and increase energy efficiency

5. Customer-Centric Smart Grid Model

The smart grid has been identified as a part of the solution in order to meet the growing demands of electricity and upgrade the electricity system infrastructure. A holistic approach is required for a successful implementation of the smart grid. This requires a comprehensive transformation from the technical, social, and economical aspects of the electricity system. This paper focuses on the social aspect where the stakeholders of the system and their interactions must first be identified. Stakeholders may be individuals, groups or constituent systems within the

System of Interest. The purpose of our research is evaluating the centricity of customers as stakeholders in the smart grid. It is also important to understand the various stakeholders' relevance and levels of influence within the smart grid. The authors observed that the NIST smart grid graphics are palatable to the general public but loses exactness. In this paper, the authors utilize a general-purpose, object oriented modeling language, the Systems Modeling Language (SysML), to begin to address this challenging problem[26]. The block definition diagram in Fig. 7 represents the domains of interest in the complex smart grid System of Systems (SoS) and is analogous to the NIST smart grid conceptual model in Fig. 4, except the authors added the environment of the system where it operates. The environmental factors are derived from the renewable energy penetration in the electricity generation sector. The overview of the smart grid domain showing the major stakeholders (customers, utility service provider, operators, and regulators), and the associated systems is important to understand the system's boundary. The smart grid SoS includes the five main systems (distribution, generation, markets, operations, and transmission) and the subsystems within the main systems as shown in Fig. 7.

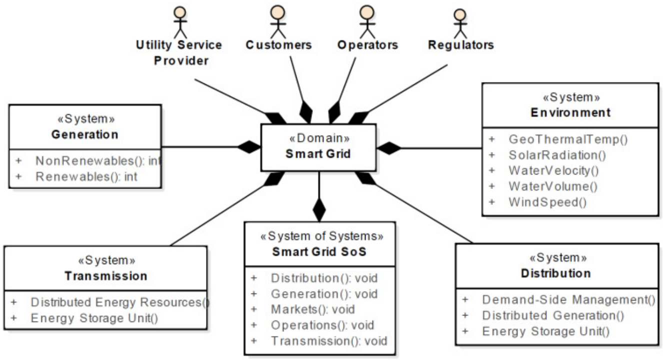

Fig. 7. Block definition diagram of the smart grid model

Based on the U.S. EIA report in 2012, one of the key stakeholders are the 145,293,840 customers in the electric industry and should to be the focus from the beginning of the smart grid evolution[27]. In the case study of the State of New York, the passive customers are evolving to becoming active stakeholders of the system. In Fig. 8, the SysML is used to understand the major stakeholders' relationships of the smart grid. In relation with the case study in section 4, the State of New York's regulators are NYSERDA, NYISO, FERC, and the NY Public Service Commission as shown in Fig. 8(a). These state and federal agencies regulate and set the standards of the state's energy industry. Fig. 8(b) shows the different utility service providers, and Fig. 8(c) displays the different types of customers in the State of New York.

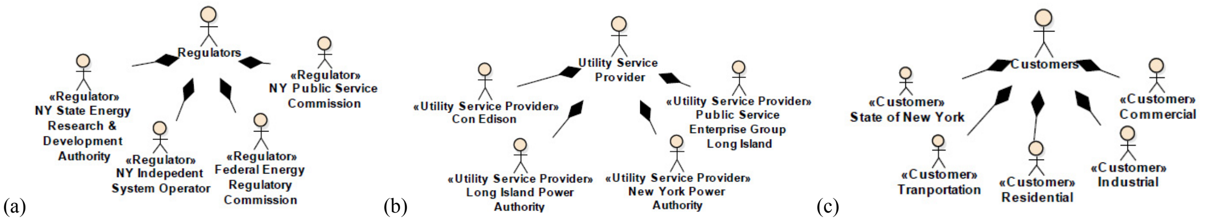

Fig. 8. Stakeholder relationships (a) Regulators; (b) Utility service providers; (c) Customers

Residential, commercial, and industry customers play an important role in realizing and ensuring the long-term success of the smart grid. Before the major penetration of renewable energies in the electricity generation sector, customers were the end-users in the one-way energy distribution network. Today, there are emerging innovative solutions and incentives to attract customers to be actively engaged and connected to the electric distribution network. The main use case diagram in Fig. 9(a) shows the association between the main stakeholders, and Fig. 9(b) shows a use case diagram containing the complete set of use cases for the system. Fig. 9(b) shows the stakeholders' participation and interaction in the smart grid system. For example, customers interact directly with the generator and the utility service provider to monitor and control real-time energy consumption based on regulation standards by the regulators. This shows the important role of customers in the involvement of the regulatory process.

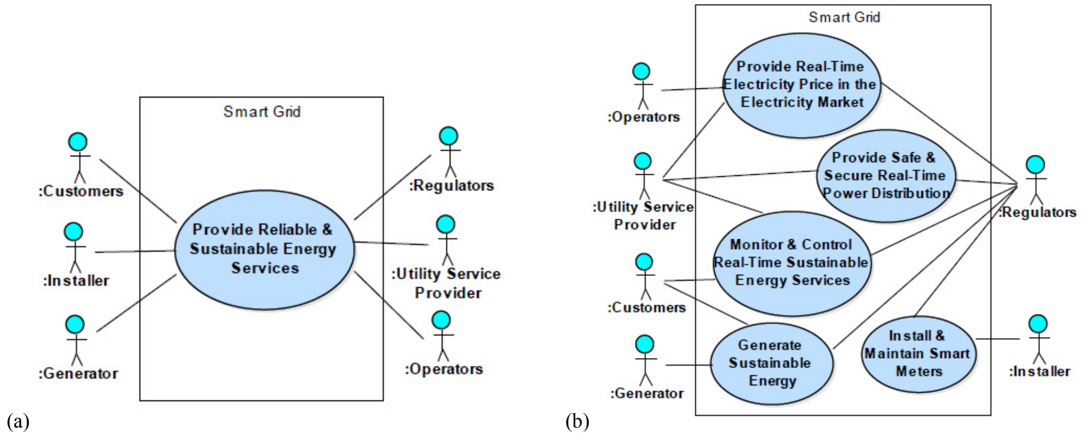

Fig. 9. (a) Main use case diagram; (b) Complete use case diagram

Based on the use case diagrams from the customer's perspective, the following activity diagram elaborates at an abstract level of detail the initiation of a customer's involvement in the smart grid evolution and the order of actions. Fig. 10 demonstrates the activities generated by the interaction between the utility service provider's mission to spread sustainable energy awareness and the customer's request for a reliable sustainable energy service.

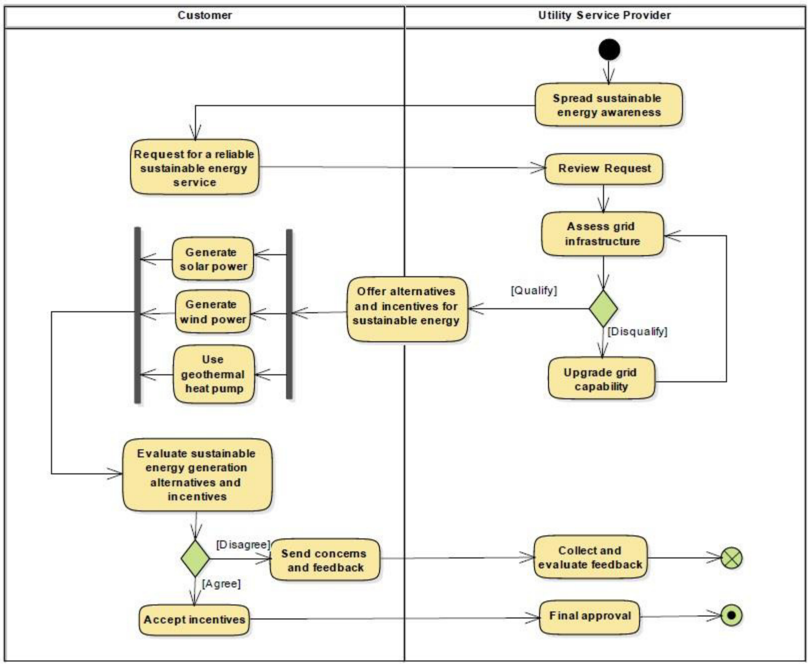

Fig. 10. Activity diagram of the customer and the utility service provider

6. Conclusion

The focus on customer centricity in the smart grid is part of an ongoing research by the authors to understand the complexity in the development of smart grid from the customer's perspective. Future research includes focusing on other stakeholder interactions and activities with different use case scenarios. The base success in today's smart grid world is the customer involvement in utilizing such sustainable technology. This formalized object oriented modeling approach may help to identify the major stakeholders, the communication flow, and their interactions. There are many incentives and rebates offered to the customers by federal agencies and utility service providers to expedite the growth of smart grid and motivate customers to be actively engaged in the smart grid. However, there may be unintended consequences of the accelerated growth of smart grid if some of the customers are not fully aware or prepared to make changes in their energy usage behaviors and take ownership of the smart grid as well. The case study on the State of New York, in particular, Con Edison's partnership with regulators and customers, is crucial to understand what the smart grid means to the customers and the collaborative efforts between the utility service provider and customers. There is a need to apply the systems engineering principles to socio-technical problems such as the smart grid energy system. For future research explorations, customer relationships in other complex socio-technical systems such as healthcare and transportation systems can be modeled using SysML to reason about the issues and simplify the complexity of the system by communicating with different stakeholders.

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