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Developing a Simulation Model for Power Demand Control Analysis and Privacy Protection in Smart Grid

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DEVELOPING A SIMULATION MODEL FOR POWER DEMAND CONTROL ANALYSIS AND PRIVACY PROTECTION IN SMART GRID

by

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ABSTRACT

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With the growing awareness of the need for Smart Grid, various countries are taking initiatives for developing Smart Grid. However, there is limited research on utilizing Smart Grid for Power Demand Control compared to the other areas such as Smart Grid communication network or renewable energy integration. Therefore, this study attempts to help the current Outage Management System by creating a Simulator that allows an intuitive power demand control analysis. Electrical usage is simulated by taking various inputs including the number of houses, family size, work and life patterns, electrical devices, time, etc. For accurate estimate of family and life style, US census data has been used. The graphical interface allows generating the electrical usage data, then it displays both individual and aggregate usage data over time. Through the two-way communication capability of Smart Grid, the devices can be remotely and dynamically controlled by the provider to meet the power supply condition. The simulator demonstrates that substantial amount of electric power can be reduced efficiently by selective demand control over Smart Grid. Furthermore, this study explores potential privacy issues in Smart Grid and suggests data anonymizationas a viable solution. Recommendations for future studies are proposed as well.

Index Terms – Smart Grid, Smart Grid Simulator, Power demand control, Privacy, Data Anonymization

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CHAPTER 1

INTRODUCTION

Given the high potential value of Smart Grid in the future energy management system, many countries are taking bold steps to set the global standards for Smart Grid [1]. For instance, the United States has set the Smart Grid Framework and Roadmap which identifies 75 standards, specifications, or guidelines through National Institute of Standards and Technology (NIST)[2]. Also, European Union (EU) has classified the Smart Metering into six categories using European Smart Meter Coordination Group (SM-CG) [3]. Moreover, NIST in US and International Engineering Consortium (IEC) are working together as an ongoing effort to set the standards for Smart Grid with Institute of Electrical and Electronics Engineers (IEEE) standards organization [4].

In order to improve or strengthen their competitive position, Asian countries are also making numerous efforts for standardizing Smart Grid. Korea, especially, played a primary role in founding the International Smart Grid Action Network (ISGAN) [5]. To construct a low-carbon and eco-friendly growth technology, the Korean Smart Grid Institute (KSGI) has made a three-phase plan and five major focus areas [6]. Even with all of these interests on Smart Grid, most of the countries are mainly focused on standardizing the policy of Smart Grid instead of establishing a comprehensive Smart Grid enabling technology which also assures privacy protection.

Therefore, this study explores the fundamental technologies of Smart Grid (discussed in chapter 2. Overview of Smart Grid) and proposes a Smart Grid Simulator (discussed in chapter 3. Smart Grid Simulator design). Furthermore, this study suggests ways to control the peak demand of electric power (discussed in chapter 4. Efficient power demand control) and to protect privacy (discussed in chapter 5. Privacy protection) by employing an data anonymization mechanism.

CHAPTER 2

OVERVIEW OF SMART GRID

As stated before, Smart Grid has recently started receiving great attention from various government organizations globally. This chapter will briefly go through the concept of Smart Grid and explore the reasons of Smart Grid becoming a rising issue among the electrical power companies. Furthermore, this chapter will explain many countries are accelerating the standardization on Smart Grid.

2.1 Concept of Smart Grid

In 2007, the Department of Commerce (DoC) was authorized by the Energy Independence and Security Act (EISA) to organize a framework for interoperability. In coordination with NIST, the framework was intended to let the Smart Grid systems and equipments operate interactively with regards to standards in the areas of Information and Communication Technologies (ICT) practices and data models [7].

According to NIST, the Smart Grid conceptual model can be categorized into seven domains: Bulk Generation, Transmission, Distribution, Customers, operations, Markets, and Service Providers [8].

- Bulk Generation is the area where massive amount of electricity is generated from renewable energy such as solar, wind, water, and so on or nonrenewable energy such as nuclear, coal, gas, and so on. It also has a capability of storing electric power for later distribution.
- Transmission carries a large sum of electricity over lengthy distances. It also

has a function of producing electric power as well as storing.

- Distribution is a network which connects Smart Grid and machines with intelligence. Distribution network enables electronic providers and consumers using Smart Grid to manage intelligent machines with intercommunicated wire or wireless system. Also, the network provides electric power to consumers in use of Smart Grid and obtains electricity from them.
- Customer represents those household, industry, and business in use of distribution network and Smart Grid. Also, customer can produce, store, and control their energy usage by exploiting Smart Grid technology.
- Operation supervises power plants, consumer network, and intelligent machines. Also, it provides information to customers.
- Market plays a role of management, trading business, and retail or wholesale market for those using Smart Grid technology in their work.
- Service provider constructs web portals and facilities while managing electricity for higher efficiency. Also, data of electric power usage is reported to consumers.

2.2 History and Current Status

An early technology of Smart Grid has partially been utilized from 1980s. For instance, one of the Smart Grid techniques, automatic meter reading, was used to monitor large groups of houses and factories in 1980s. Later on, advanced metering infrastructure was developed for power plant and/or electricity provider in 1990s as an initial stage model of Outage Management System (OMS) using Smart Grid [9].

However, Electric Power Research Institute (EPRI) was the one who representatively started studying Smart Grid in early 2000. Later on, the base plan of intelligent Smart Grid was announced in 2003, *i.e.*, CEIDS Master Plan [10] and US Department of Energy Grid 2030 [11]. Figure 1 shows the research corporations and associations who have studied intelligent Smart Grid.

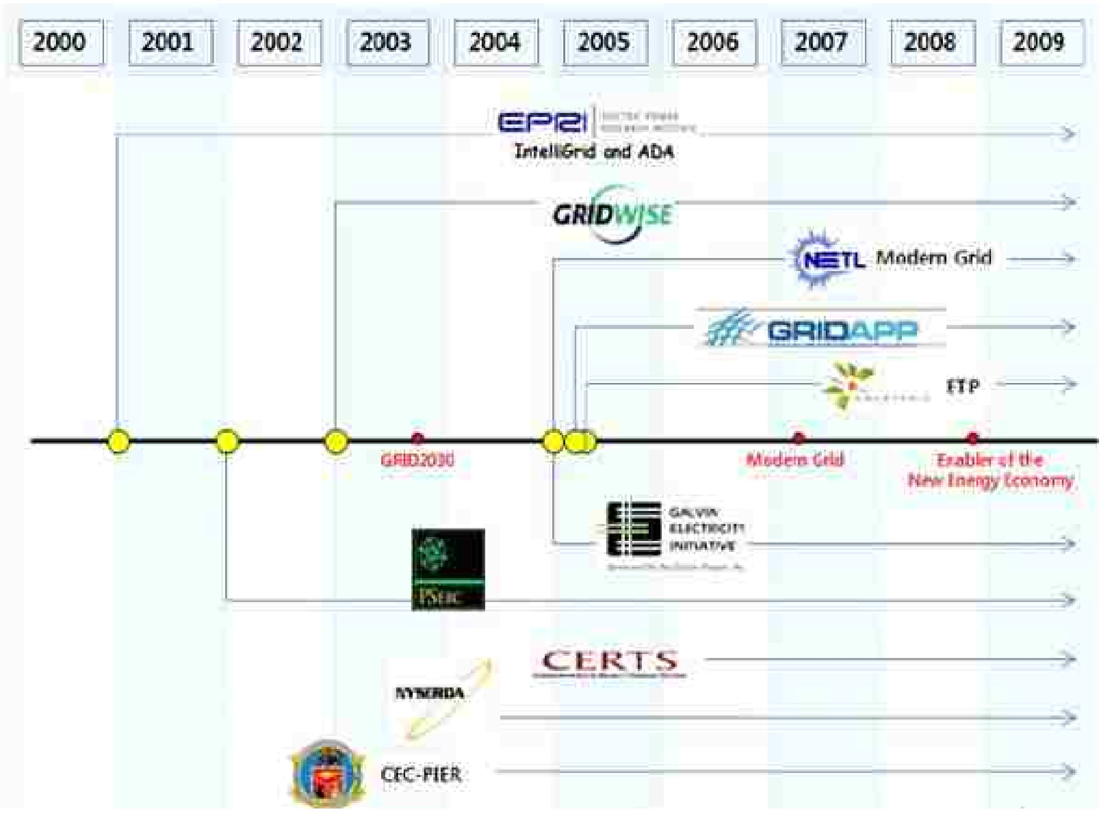


Figure 1 Smart grid study history [12]

In 2007, the United States passed EISA, a federal energy management program that focused on reducing the usage of energy while increasing the efficiency of energy. International Smart Grid Action Network (ISGAN) was established in 2011. It is comprised of twenty-three countries (USA, UK, Korea, Germany, Japan, China and so on) and three international organizations (International Energy Agency [IEA], International Partnership for Energy Efficiency Cooperation [IPEEC], International Renewable Energy Agency [IRENA]) [13]. The primary focus of the organizations mentioned above is to create and improve Smart Grid techniques and policies. Table 1 shows the major work of ISGAN.

Table 1 ISGAN United project being processed among joint member countries within four subdivisions [13]

Classification	**Authority**	**Member Country**	**Activity**
Inventory of world smart grid	USA, Italy	Korea, Belgium, Canada, China, France, Japan, UK, EC, IEA	Sharing country project and policy of smart grid
Case studies of Smart grid	Korea, Japan, EC	Canada, China, France, Germany, Sweden, Norway, Italy, UK, USA	Sharing demonstration study and introduction of smart grid
Cost-benefit analysis	Undecided	Canada, India, Sweden, Italy, UK, USA, Mexico, EC, Korea	Analysis effects of existing power line Compare with smart grid
Providing insights of decision making	Norway	Belgium, India, USA, Korea	Provide information package to decide policy making

In recent years, starting from 2010, many countries are making on effort to join international organizations for constructing international standards on smart grid and developing smart grid techniques.

2.3 Needs and benefits

The majority of countries in the world are in need of more power [14] [15]. For instance, figure 2 shows that the total consumption of energy in US has been increasing steadily almost every year. As more electrical appliances are invented and produced, the amount of electric power used by factories and households has increased. Yet, the efficiency of power is low due to the outdated power line. The transmission systems of electricity in Europe that are currently operating are mostly built back in late 1970s, hence, either need to be mended or replaced [16].

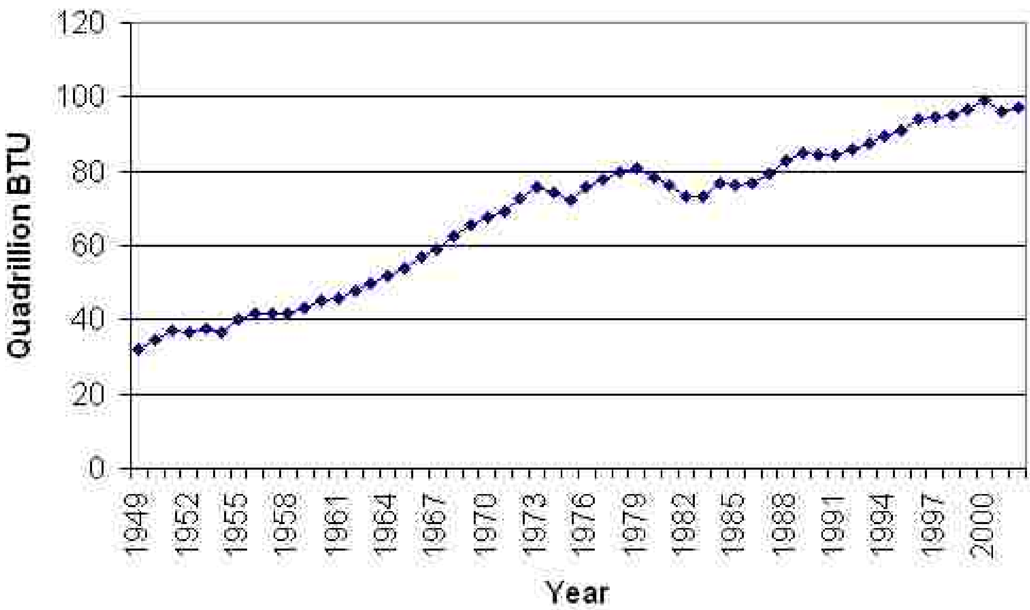


Figure 2 Total US Energy Consumption [17] (measured in quadrillion BTU)

Moreover, reducing carbon dioxide is becoming a global issue for conserving the environment [18]. According to EU Energy and Climate Package, three major targets that meet the terms of EU energy policy (i.e. security of supply, sustainability and market efficiency) were set for 2020 and beyond. These targets are: to reduce Green House Gas (GHG) emissions by 20% compared to the levels of 1990s, to increase the renewable energy sourcesin EU twenty-seven energy mix from 6.5% of today's to 20%, and to reduce the amount of primary energy used by 20% (to save 13% compared to the levels of 2006) [19].

For the above reasons, developing Smart Grid for power plant and/or electricity provider is becoming inevitable. United States is also confronting a similar situation as Europe. Due to depreciated electricity transmission systems, a large volume of electric power gets wasted. Even a few major blackout incidents have occurred causing a mixture of damages which include inconvenience to consumer, financial damage, and so on [20]. Table 2 presents the degree of damage caused by a large scale of blackout.

There are two fundamental approaches to solve this situation. One way is to build enough power plants in order to accommodate the needs of electric power or to replace the previous old power lines to new ones [22]. However, this solution requires a lot of money, time and efforts for either constructing power plants or changing power lines. The other way is to utilize Smart Grid technology. Smart Grid has a great potential to make the most of electricity. Not only high efficiency of electric power can be anticipated but also the usage of time and money can be minimized if Smart Grid is exercised properly.

Table 2 Damage of Blackout in USA [21]

Year	**Location**	**Damage Scale(Consumer)**
06/15/2000	San Francisco	97,000 people
01/17/2001	The northern California	200thousand~500thousand people
01/18/2001	The north central California	Five million people
03/19/2001	California	1,500thousand people
08/14/2003	The eastern America and Canada	Fifty million people USA:4billion~10billion dollars Canada: GDP 0.7% decrease, 23 hundred million dollar(Canada)
09/08/2011	The south America and The northern Mexico	Six million people A hundred and eighteen million dollars

Four main benefits are identified in relation to Smart Grid technology [23]:

A. Power Supplier

According to the “Final Report on the August 14, 2003 in the United States and Canada”, an average cost of massive blackout incidents is $10 billion per event. Moreover, Electric Power Research Institute (EPRI) noted that the impact of power disturbances toward the USA economy is estimated to be $100 billion as an annual cost. However, these costs can be reduced with a proper use of Smart Grid. For instance, Smart Grid technology enables power plant and/or electricity provider to collect customer's data in real time and adjust customer's power usage. There are two advantages associated with producing precise amounts of electric power based on customer's data: minimized cost of storing overproduced electric power and less discharged amount of overproduced electricity. Furthermore, customer's data in real time can be helpful for early detection of power issues. Also, the frequency of blackout occurrence can be substantially reduced by controlling customer's electronic usage at peak time.

B. Customer

Smart Grid technology enables customers to receive detailed information about their power usage and related cost in real time. Hence, customers can possibly plan the course of action for managing their usage of electricity and cost of their electric charges: avoiding high-price time frame and reducing the usage of electricity. Moreover, customers who are interested in renewable energy can choose their power sources from solar, wind, or water instead of nuclear or coal. In this way, customers can personalize their options on managing their electric power usage which fits their budget and preference. Additionally, smart meter derived from Smart Grid technology provides customers convenient options for controlling their home appliances. Even when customers are away from their home, they can turn off electronics by simply using their personal devices, such as cellular phone, ipad, laptop, and so on.

C. Efficiency

According to the projection of EPRI, practicing Smart Grid technology could reduce the total U.S electricity consumption by 56 to 203 billion KWh's by 2030 (1.2~4.3%). Besides, Smart Grid technology facilitates high efficiency by adequately supplying electricity on demand and reducing transmission and distribution losses of electric power. Smart Grid with self-adjustment system could easily detect and restore problems through continuous self-scan. Unlike previous systems, Smart Grid enables electronic providers and customers to be directly connected. Consequently, distributed power supply system can possibly improve utilization of renewable energy by lowering irregular sources such as air volume and sunshine [24].

D. Environment

As a higher efficiency on renewable energy can be assured using Smart Grid technology, nuclear or coal energy will be able to be substituted with renewable energy. By doing so, the amount of carbon dioxide, green-house gases, and pollutant that are associated with nuclear or thermoelectric power plant can be substantially reduced. Also, EPRI noted a great potential of benefits associated in using electric-powered vehicles supported by Smart Grid technology and estimated that electric vehicles can reduce emissions of carbon dioxideby 60~211 million metric tons in 2030. These occasions explains the reason of Smart Grid technology being a great help to eco-friendly environment.

CHAPTER 3

SMART GRID SIMULATOR DESIGN

This chapter will illustrate the algorithms utilized in the Smart Grid Simulator and explain its design principles.

3.1 Computer simulation

Computer simulation refers to the research method of exploring various systems in real-world. This is generally done by evaluating software which is constructed to imitate operations or characters of system. From a practical point of view, computer simulation carries out numerical experiments with a purpose of providing abetter understanding on system operation under given circumstances. Although it can be utilized in various kinds of system research, computer simulation shows its great magnitude when used in a study of complex systems. There are eight major categories within the simulation [25]. They are “General Purpose Software”, “Manufacturing Oriented Software”, “Planning & Scheduling Software”, “Special Purpose Modeling Software/ Simulators”, “Simulation Environments”, “Animators”, “Rapid Modeling Tools”, “Simulation Support Software”. Among these categories, this study chose to employ “Simulation Environments” as it is best applicable to Smart Grid Simulator. Consumers’ electricity usage was used as the data for the input data analysis, and the demands control process of consumers’ home appliances was similar to the scenario management of Simulation Environments [26].

3.2 Data

Data utilized in this study is named into five groups: Family Type, House Type, Person Type, Electronic Device, and Master Usage Data. In order to better understand how these sources are grouped and applied, supplementary explanation will be made throughout this chapter. Person Type and House Type was formed based on Family Type. Likewise, Master Usage Data was created by adding three groups of data: House Type, Person Type, and Electronic Device Data. Finally, each house was made based on Master Usage Data. In order to simulate electrical usage of customers, we produced data about pattern of personal life, number of family members, and size of houses. Also, these sources are each named into Person Type, Family Type, and House Type. Person Type stands for time frame of work schedule. Family Type refers to number of house members. House Type represents size of house. We will discuss these data in depth in the following.

3.2.1. Family Type

Consumption of electricity in each household differs depending on its family members. For example, the kind of and the number of electrical devices vary depending on the number of household members and their ages. Hence, it is necessary to divide Family Type using these two segments.

Based on "U.S. Census Bureau: Households, by Type, Age of Members, Region of Residence, and Age of Householder: 2011" [27], presented in table 3, we rearranged "all household by size" into seven parts and named them as Family Type. They are single senior, single regular, dual senior, dual regular, couple with one child, Couple with two children, Couple with three children or more. Household with one member was divided into two subdivisions of Family Type: single senior and single regular. Household with two members was also divided into two sections of Family Type: dual senior and dual couple. Some types of household by size had insignificant total number to be considered as an individual Family Type and had to be merged. Therefore, household with five, six, and seven or more members were combined to create a Family Type: couple with three children or more. Table 4 summarized the family types. A more detailed explanationon Table 4 is given below.

Table3 Households, by Type, Age of Members, Region of Residence, and Age of Householder: 2011 [27]

All household by size	Total	Age of Householder											Mean age
		Under 20 years	20-24 years	25-29 years	30-34 years	35-39 years	40-44 Years	45-49 years	50-54 years	55-64 years	65-74 years	75+ years	
One member	32,723	109	1,336	2,244	1,913	1,682	1,870	2,596	2,976	6,693	4,805	6,498	55.9
Two members	39,718	188	1,887	2,908	2,327	1,887	2,111	2,977	4,157	9,790	6,823	4,662	53.9
Three members	18,529	207	1,126	1,891	2,132	1,950	2,044	2,373	2,344	2,904	1,030	527	44.4
Four members	15,910	134	578	1,412	2,131	2,675	2,732	2,563	1,732	1,418	352	183	42.0
Five members	7,346	71	262	561	1,073	1,352	1,384	1,132	671	602	156	83	41.6
Six members	2,773	47	100	203	399	483	503	360	271	263	108	36	42.2
Seven or more members	1,684	15	79	112	265	305	272	219	159	158	74	25	42.3

Table4 Family type

Family Type	Number of Member	Number of House	Percent (%)
Single senior	One	11,303	9 %
Single regular	One	21,419	18 %
Dual senior	Two	11,485	10 %
Dual couple	Two	28,232	24 %
Couple w/ 1 child	Three	18,529	16 %
Couple w/ 2 children	Four	15,910	13 %
Couple w/ 3+ children	Five +	11,803	10 %

First four subcategory of Family Type on Table 4 was created by regrouping sources of Table 3 in regards to two following options: number of family members and age of householder. Single senior segment was derived from counting the total number of family with one member who is an age of 65 or over. The percentage of each type was created by dividing the total count of each subgroup which has sufficient conditions by total sum of all Family Type. Single regular type refers to the total count of family with one member who is 64 years or less. Dual senior type was obtained by adding all of the families with two members including householder with age 65 or over. Also, families with two members and householder of age 64 or less became Dual couple type. Finally, families with more than three household members were assumed to have a child or children. For example, families with five members were considered to have three children. After this process, Table 4 was constructed as Family type data.

3.2.2. House type

Generally, the volume of electric power usage differs depending on size of the houses. For instance, families with higher number of family members tend to live in bigger sized houses resulting in higher usages of electric power. Also, families with children are expected to use more of various kinds and a higher number of home appliances compared to families without a child, which consequently leads to a higher usage of electricity. With these general ideas in consideration, House Type was categorized into four sections based on Family Type. They are Apt, Small, Medium, and Large. Each Family Type was set as 100 percent and House Type was divided accordingly as a total of 100%.

The majority of single tend to live in apartment or small house while families with a child or children live in bigger houses. The percentage of House Type is set to be varied by ages of family members. For a convenience of this study, there is an assumption made that families with older age family members, noted as senior, will be wealthier and, hence, live in a bigger house than families with younger age, noted as regular. Table 5 was formed based on these facts.

Table 5 House Type

House Type / Family Type	Apt (<1200 square feet)	Small (<2000 square feet)	Mid (<3000 square feet)	Large(3000+ square feet)
Single senior	50 %	45 %	5 %	0 %
Single regular	60 %	35 %	5 %	0 %
Dual senior	25 %	35 %	35 %	5 %
Dual couple	40 %	35 %	20 %	5 %
Couple w/ 1 child	10 %	45 %	35 %	10 %
Couple w/ 2 children	5 %	35 %	45 %	15 %
Couple w/ 3+	0 %	10 %	40 %	50 %

Table 6 Family-House Type (%) (Family Type (%) X house Type (%))

House type / Family type	Apt (<1200)	Small (<2000)	Mid (<3000)	Large (3000+)
Single senior	4.5 %	4 %	0.5 %	0%
Single regular	10.8%	6.3 %	0.9 %	0%
Dual senior	2.5 %	3.5 %	3.5 %	0.5 %
Dual couple	9.6 %	8.4 %	4.8 %	1.2 %
Couple w/ 1 child	1.6 %	7.2 %	5.6 %	1.6 %
Couple w/ 2 children	0 %	3.9 %	6.5 %	2.6 %
Couple w/ 3+	0 %	1.0 %	4.0 %	5.0 %
percentage	29 %	34.3%	25.8%	10.9%

Table 6 was artificially constructed by adding percentage (%) of Family Type in Table 4 and percentage (%) of House Type in Table 5. The process of joining them into Table 6 as a complete percentage table was necessary as it enables easier union with Person Type.

3.2.3. Person Type

Table 7 shows the type of persons and their activity hours.

Table 7 Person Type (PersonTypeFile)

Family Type / Person Type	Single senior	Single regular	Dual senior	Dual couple	Couple w/ 1 child	Couple w/2 children	Couple w/3+ children
DayTime	80 %	40 %	70 %	50 %	60 %	70 %	70 %
NightTime	10 %	30 %	20 %	40 %	30 %	20 %	20 %
AnyTime	10 %	20 %	10 %	10 %	10 %	10 %	10 %
Percentage	100%	100%	100%	100%	100%	100%	100%

Activity hours such as primary work schedule or school hours of family members can be a segment that decides time frame of major usage on home appliances. In other words, it stands for the likelihood of electric power not being consumed by electronic devices as household members are away from their home. As a result, working hours surely can play a role in determining the major electricity usage time frame and the volume of electric power usage. In order to decide working hours of family members, a couple of assumptions were made in relation to their ages and the presence of a child or children in a family. For example, it was assumed that Seniors who are 65 and over will have a tendency of working or being away in DayTime while Regulars 64 and less will tend to stay out more in NightTime with high frequency of random work schedule than Seniors. Also, households with a child or children will likely to have more of DayTime work schedules than those with no child. With these assumptions in consideration, each Family Type was proportionally divided into Person Time percentage resulting in Table 7.

3.2.4. Electric Device

Table 8 describes the characteristics of chosen electric devices.

Table 8 Virtual Electric Devices

Electric Device	Element	Apt	Small	Mid	Large
TV	Watt	150	230	150	230
	Count	1	1	2	3
	Frequency	60 min			
	usageTime	180 min			
Fridge	Watt	144	182	144	182
	Count	1	1	2	3
	Frequency	15 min			
	usageTime	600 min			
Computer	Watt	212	212	212	212
	Count	1	2	3	4
	Frequency	90 min			
	usageTime	360 min			

Type, sizes, and numbers of home appliances can vary depending on the size of houses. Generally, larger houses tend to hold bigger electronic devices such as refrigerators, televisions, and so on compared to those in smaller houses. Also, larger houses may have more appliances with a variety of kinds while smaller houses have less electrical device with fewer selection. This implies the fact that houses or apartments with larger square feet are prone touse higher volume of electric power than those with smaller square feet.

There are a few appliances like computers tough to apply this supposition as they may vary by the number of household family. However, with the assumption made on Family Type that household with many family members will live in a large house rather than a small one, these electronic devices were proportionally increased in number same as the others.

Depending on the function of electrical devices, time period of electric power usage differs. To put it simply with examples, toaster will be used more in the morning while night-light tends to be used more in the evening. Home appliances such as television or computer continuously consume electricity from the moment they are turned on until they are completely turned off. Yet, fridges in most cases operate occasionally when their internal temperatures are not cold enough to reach the designated temperature. Due to the characters for these appliances, frequencies for television and computer was set as the number of times they get turned on whereas frequency for fridge was set to be the number of automatic adjustments made for maintaining its internal temperature. This intermittent operation of refrigerator is shown as a periodic low peaks in Figure 15. By adding the total time of usage within 24-hour period, usageTime for each electric device was generated and arranged into Table 8.

House Type has a substantial influence on the amount of electric power usage. Person Type also plays a similar role to the major time frame of electricity usage. Originally, these two types of data along with Family Type data were combined. Then, the united data was adjusted in regards to characters of each appliance. As a result, Master Usage Data was constructed. Figure 3 displays the process of Master Usage

Data creation.

Among all the processes involved in creating Master Usage Data, correlation between Family-House Type and Person Type (FamilyHousePersonType) is the most fundamental part that needs attention.

3.2.5. Master Usage Data (Family-House-PersonType Data)

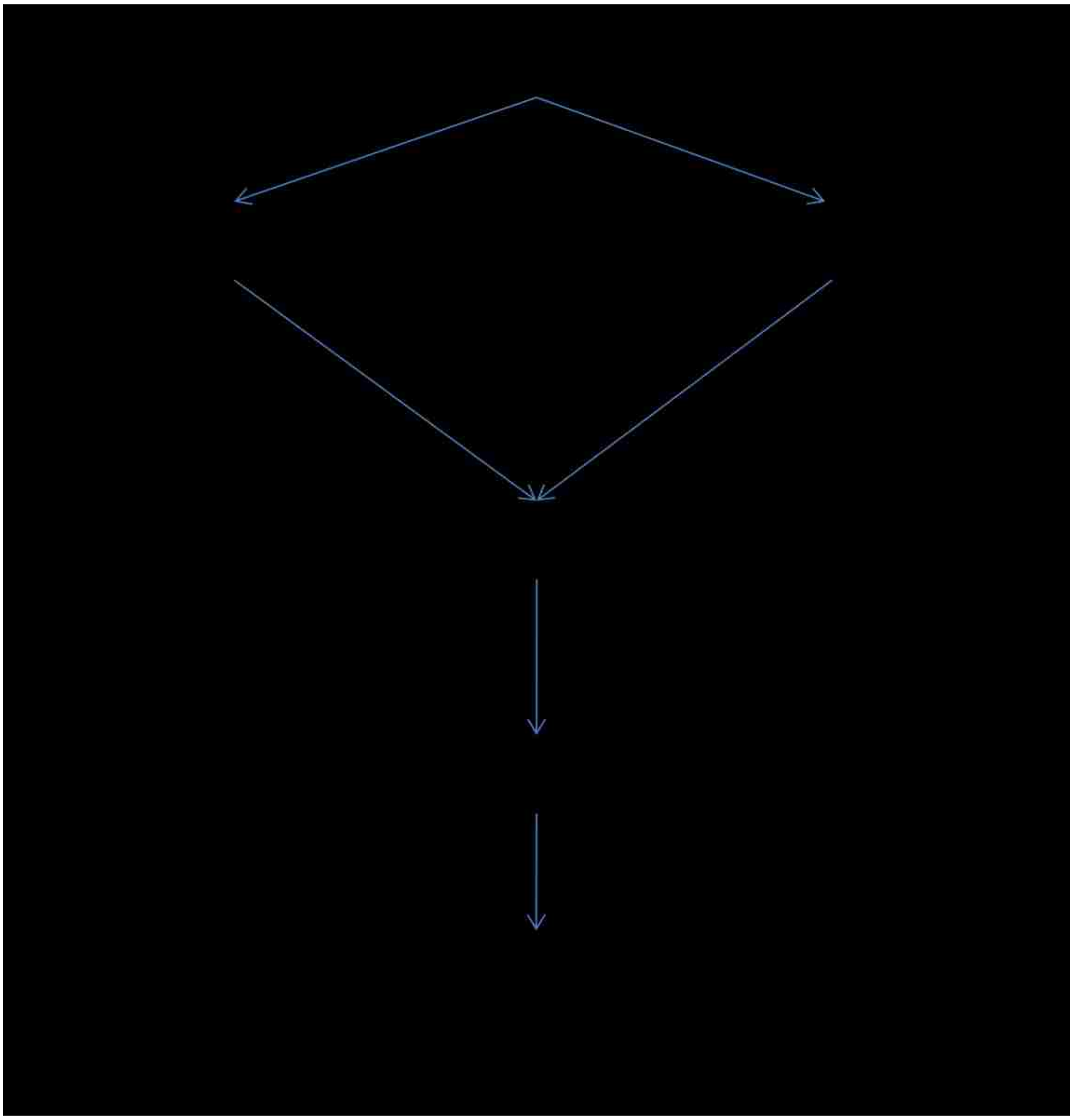


Figure 3 Process of Master Usage File production

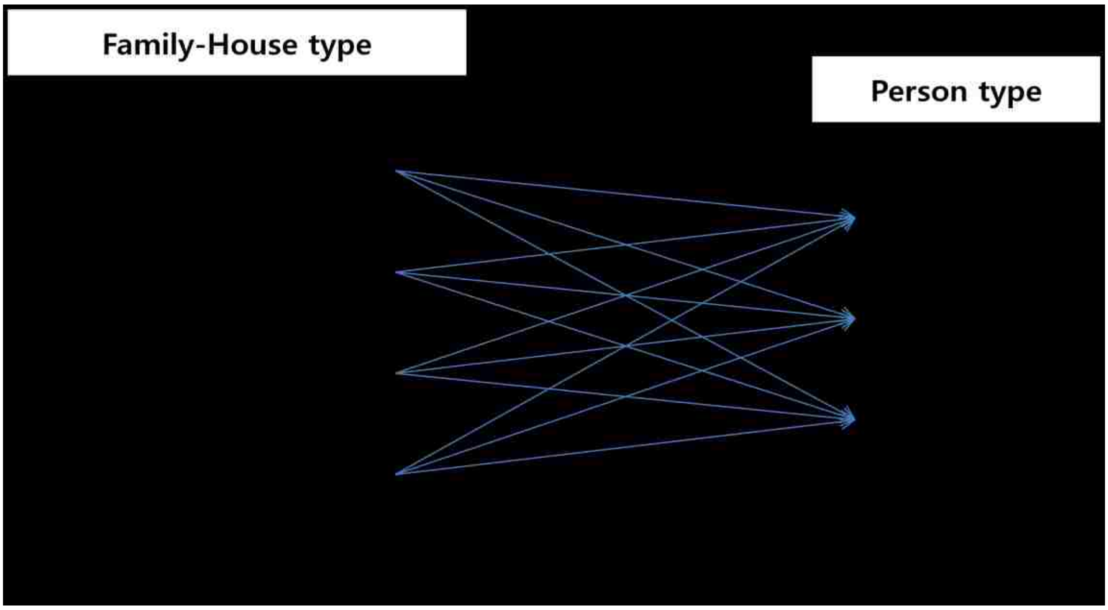
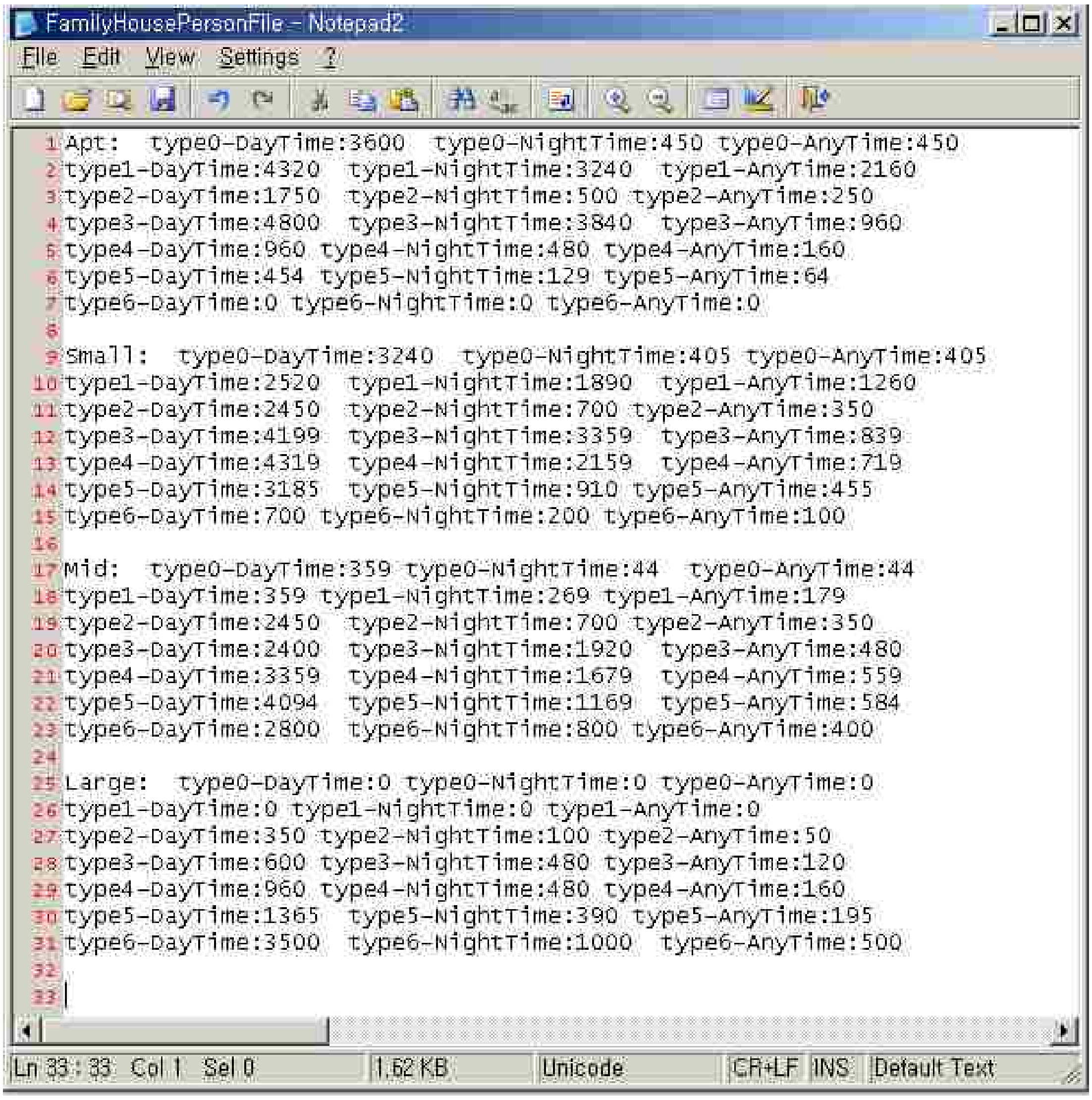


Figure 4 Family-House Type and Person Type (correspondence of N: M)

There were a couple of steps followed in order to create the data of FamilyHousePersonType. First of all,Table 6 was formed after uniting the percentages of Family Type and House Type. Secondly, the percentage of houses in each House Type was obtained after multiplying the total number of houses by each percentage inTable 6. The final products were named as numberOfApt[familyType], numberOfSmall[familyType], numberOfMid[familyType], and numberOfLarge[familyType]. Although these finishing products will represent the total number of houses in each House Type later on the process, they are named this way as total number of houses is not decided yet. Lastly, the percentage of houses in each house was corresponded with Person Type as shown on Figure 4 resulting in FamilyHousePersonType data.



```
Apt:  type0-DayTime:3600  type0-NightTime:450 type0-AnyTime:450
type1-DayTime:4320  type1-NightTime:3240  type1-AnyTime:2160
type2-DayTime:1750  type2-NightTime:500 type2-AnyTime:250
type3-DayTime:4800  type3-NightTime:3840  type3-AnyTime:960
type4-DayTime:960 type4-NightTime:480 type4-AnyTime:160
type5-DayTime:454 type5-NightTime:129 type5-AnyTime:64
type6-DayTime:0 type6-NightTime:0 type6-AnyTime:0

Small:  type0-DayTime:3240  type0-NightTime:405 type0-AnyTime:405
type1-DayTime:2520  type1-NightTime:1890  type1-AnyTime:1260
type2-DayTime:2450  type2-NightTime:700 type2-AnyTime:350
type3-DayTime:4199  type3-NightTime:3359  type3-AnyTime:839
type4-DayTime:4319  type4-NightTime:2159  type4-AnyTime:719
type5-DayTime:3185  type5-NightTime:910 type5-AnyTime:455
type6-DayTime:700 type6-NightTime:200 type6-AnyTime:100

Mid:  type0-DayTime:359 type0-NightTime:44  type0-AnyTime:44
type1-DayTime:359 type1-NightTime:269 type1-AnyTime:179
type2-DayTime:2450  type2-NightTime:700 type2-AnyTime:350
type3-DayTime:2400  type3-NightTime:1920  type3-AnyTime:480
type4-DayTime:3359  type4-NightTime:1679  type4-AnyTime:559
type5-DayTime:4094  type5-NightTime:1169  type5-AnyTime:584
type6-DayTime:2800  type6-NightTime:800 type6-AnyTime:400

Large:  type0-DayTime:0 type0-NightTime:0 type0-AnyTime:0
type1-DayTime:0 type1-NightTime:0 type1-AnyTime:0
type2-DayTime:350 type2-NightTime:100 type2-AnyTime:50
type3-DayTime:600 type3-NightTime:480 type3-AnyTime:120
type4-DayTime:960 type4-NightTime:480 type4-AnyTime:160
type5-DayTime:1365  type5-NightTime:390 type5-AnyTime:195
type6-DayTime:3500  type6-NightTime:1000  type6-AnyTime:500
```

Figure 5 Example of FamilyHousePerson Type

The data file is created in textual format for human readability and quick debugging. Figure 5 is an end product of hundred thousand houses in total being applied with Family-House Type and Person Type with the use of N: M interrelation as demonstrated in Figure 4. House Type was referred to Apt, Small, Mid, and Large. Type with a range of 0~6 stands for Family Type. Also, DayTime, NightTime, and AnyTime represent Person Type. As shown on Figure 5, there are some data values expressed in ‘0’. These were appeared as ‘0’ when combination of Family-House Type and Person Type was impossible. For instance, families with numerous household members living in APT will result in ‘0’ value as they were excluded in Family-House Type data ofTable 6.

Data derived from the process, Family-House-Person Type, were applied into each electronic device. Time Gen which randomly assigns operation time of appliances was then entered to obtain electric power usage in watt for every minute. Master Usage File was constructed which were used as a foundation of building houses that will be utilized in Smart Grid Simulator.

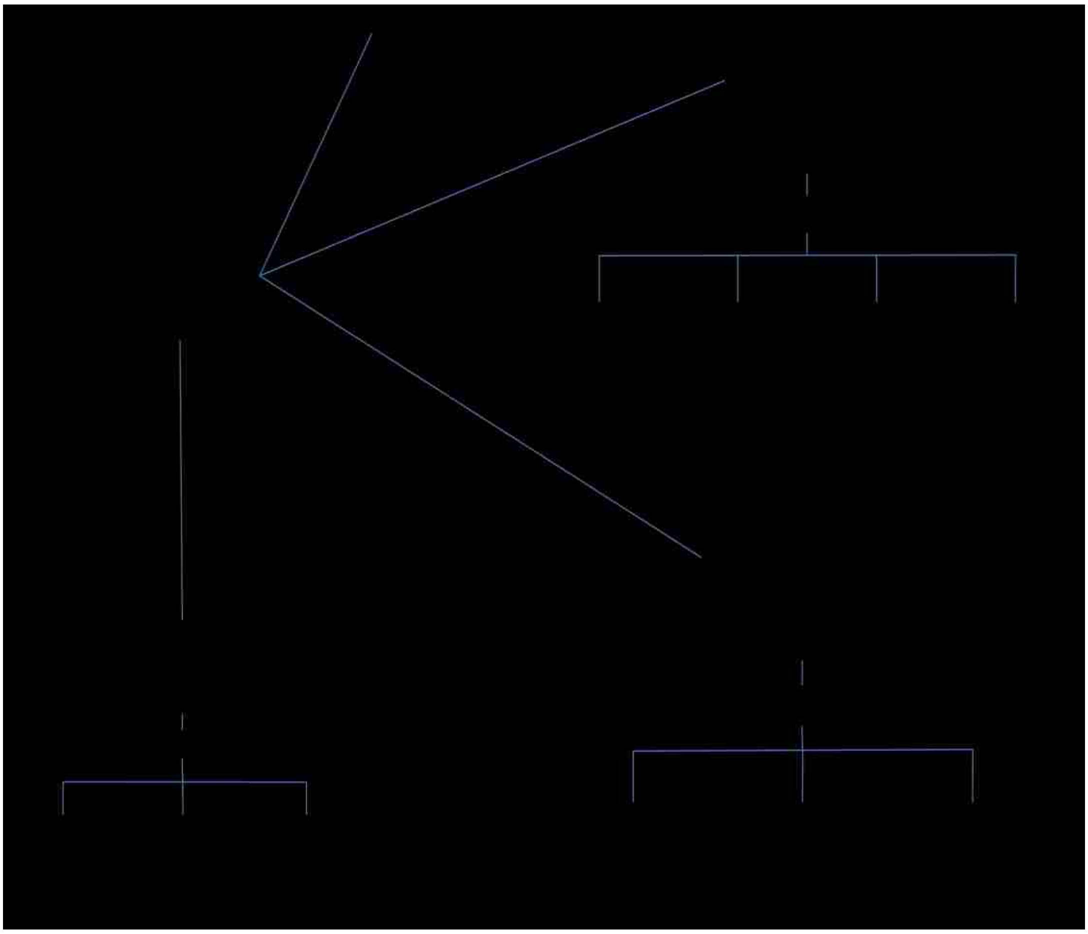


Figure 6 UML of Master Usage File

Figure 6 illustrates realization of Master Usage File with a use of Unified Modeling Language (UML) [28]. UML shows the process of combining Family Type, House Type, and Person Type data with the use of Generator. It also displays the creation of time usage in relation to each appliance using Time Gen. More concrete information of UML will be presented in APPENDIX 1.

3.3 How to operatethe Smart Grid Simulator

3.3.1 Implementation

Smart Grid Simulator was created by utilizing Windows Application Programming Interface with C++. Also, Microsoft Visual Studio 2010 Professional was selected as a development tool [29]. For development environment, Microsoft Windows XP Professional version 2002 Service Pack3 was chosen.Test environment also employed Microsoft Windows XP Professional version 2002 Service Pack3. The computer hardware utilized in testing the Smart Grid Simulator is equipped with AMD Athlon ™ II X4 620 Processor 2.60 GHz and 3.25 GB RAM.

A discrepancy in numbers of Input House and Output House is due to the fact of Mater Usage Data file being comprised in percentage. This is a phenomenon that happens during the production of Master Usage Data since family and house unit need to be presented as whole numbers. A formula can express this condition by:

IH=Input House

OH=Output House

$$\text{Number of Output House} = \sum \lfloor \text{OH} \rfloor \leq \sum \text{IH}$$

Table 9 Time table for creating house and electric devices data

Upper bound number of Input House	Output House	Electric Devices	Run Time	File size
100	62	186	2 sec	73 KB
1,000	948	2,844	17 sec	1,095 KB
10,000	9,796	29,388	3 min	11,366 KB
100,000	98,178	294,534	30 min	113,450 KB

Table 9 exhibits the production time along with the size of each file for generating Master Usage Data. The reason for not creating an entry fora million houses is that the size of the resulting file becomes more than 1GB to include the data for three million appliances. It becomes a problem since Notepad or Microsoft Office Word 2007 program can only open up to 512 MB of file. Although it is possible to make a file of data on a million houses with a total size of 1.09GB, a hundred thousand houses were set as the highest limit since data file cannot be read. However, this limitation can be easily circumvented by creating multiple data files. Figure 7 shows the production of HouseID, electronic device, priority of electronic device, and time range of electricity.

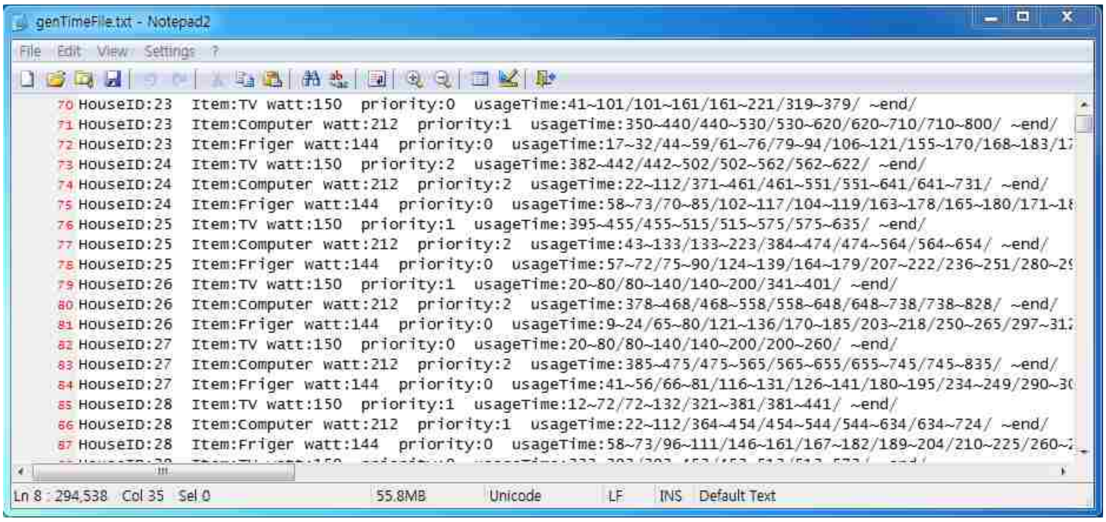


Figure 7 genTimeFile.txt – data of house

Time range of electricity usage was produced using algorithm of Master Usage Data, then, was categorized in ascending order using Bubble Sort for easier way to draw a graph. House ID was also ranked in ascending order. Priority was assigned randomly. Further explanation on these data will be made in next chapter.

3.3.2 Create House

In order to test Smart Grid Simulator, total number of houses is needed as the input data. Hence, we will be modifying sources of Master Usage File presented in Figure 3 so that they can be entered in CountHouse of Smart Grid Simulator. We set a standard unit of CountHouse to 100. A rationale for deciding this specific number is that house needs to be presented as a whole number. Since Master Usage File data is noted as percentage, outcome value of House may accompany decimals if a number smaller than 100 is selected for standard unit of CountHouse.

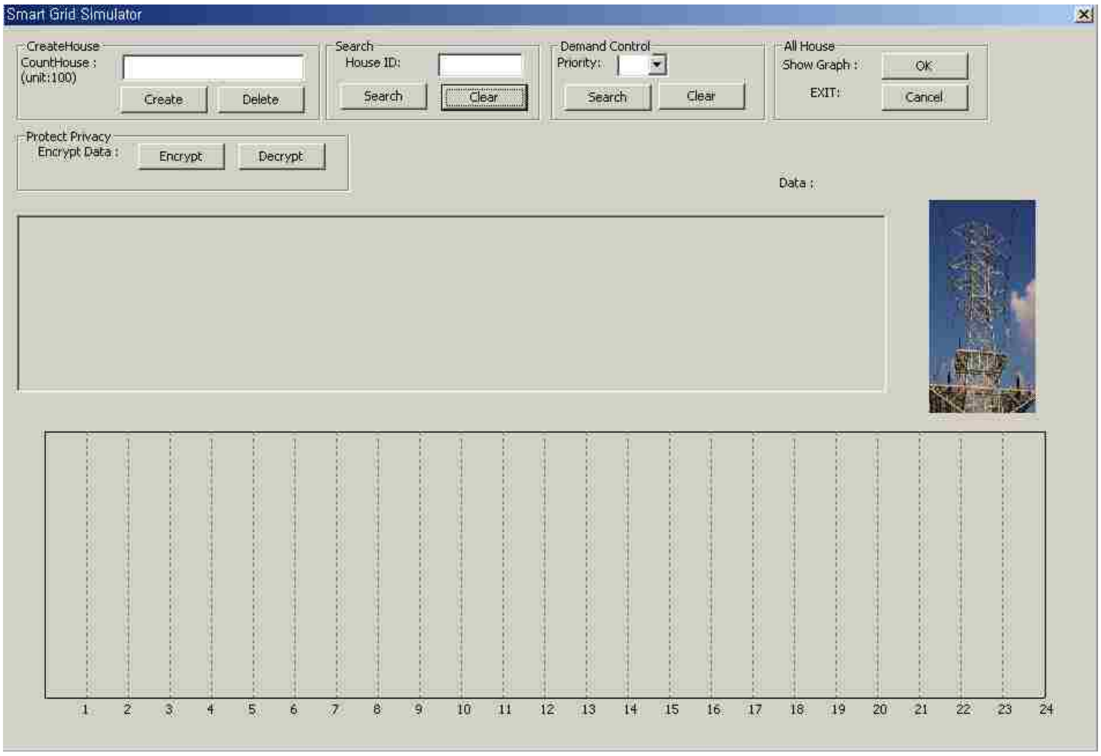


Figure 8 Simulator

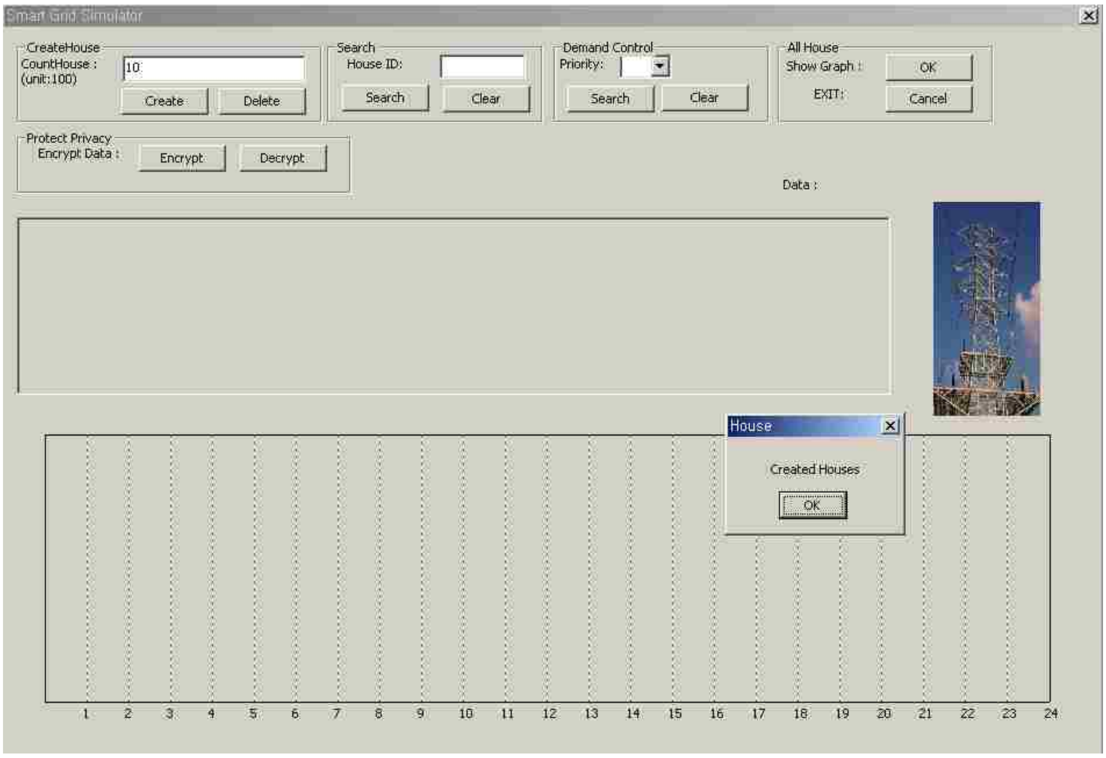


Figure 9 Smart Grid Simulator (Created Houses)

Figure 9 was created by entering the number 10 on CountHouse and pressing the Create button. Although only about a thousand of houses were produced with the process, total counts of data become three thousands since three electronic devices per house are assigned. These appliances refer to television, computer, and fridge. There are only about a thousand of houses. Yet, genTimeFile contains approximately three thousands of data in total as it includes three appliances per house. These data became a foundation for operating Smart Grid Simulator.

3.3.3. Search House by House ID

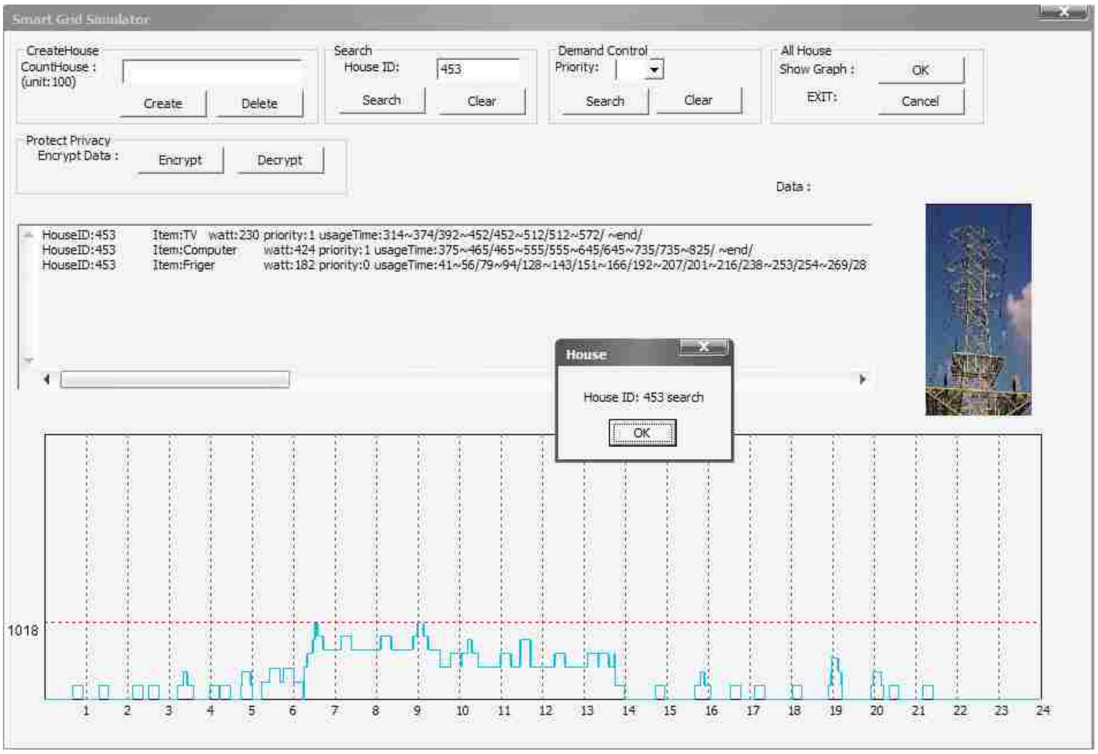


Figure 10 Smart Grid Simulator (Search House)

In order to confirm whether electronic device is working properly or not and how each House data was made, House Search function is created. Figure 10 displays how House Search function works infinding a single house from houses in genTimeFile. When HouseID number is typed in the box, Data Box displays HouseID, name, watt, priority, and usageTime of Home appliance. HouseID represents each house which includes electric devices. Priority indicates order of priority in electric power supply among three of the home appliances set by consumer. Priority ‘0’ indicates the top priority in electric power demand as they need a constant supply of electricity to properly operate. Electric devices such as refrigerators with highest potential damage when blackout occurs were set as ‘0’ in priority as they constantly consume electricity. Unit of usageTime was set as a minute. Total amount of 1440 minutes were calculated by multiplying 60 minutes with 24 hours. Graph under the Data Box shows when and how much electricity is consumed within 24 hours. X-axis indicates usage time with a unit of hour. Y-axis signifies usage amount with a unit of watt.

Figure 10 displays detailed information on HouseID 453. The major electricity usage time frame for HouseID 453 is in the morning and afternoon, especially from 6AM to 9AM, with highest point of electric power usage as 1018 watts HouseID 453 has priority ‘0’ for refrigerator while both television and computer were set to priority ‘1’.

3.3.4. Show All House Graph

To see total amount of electronic usage, we created Show All House Graph function. This function shows the graph of all house electric usage and limit of output of electricity provider. Figure 11 demonstrates the result of clicking OK button on Show Graph under the All House box.

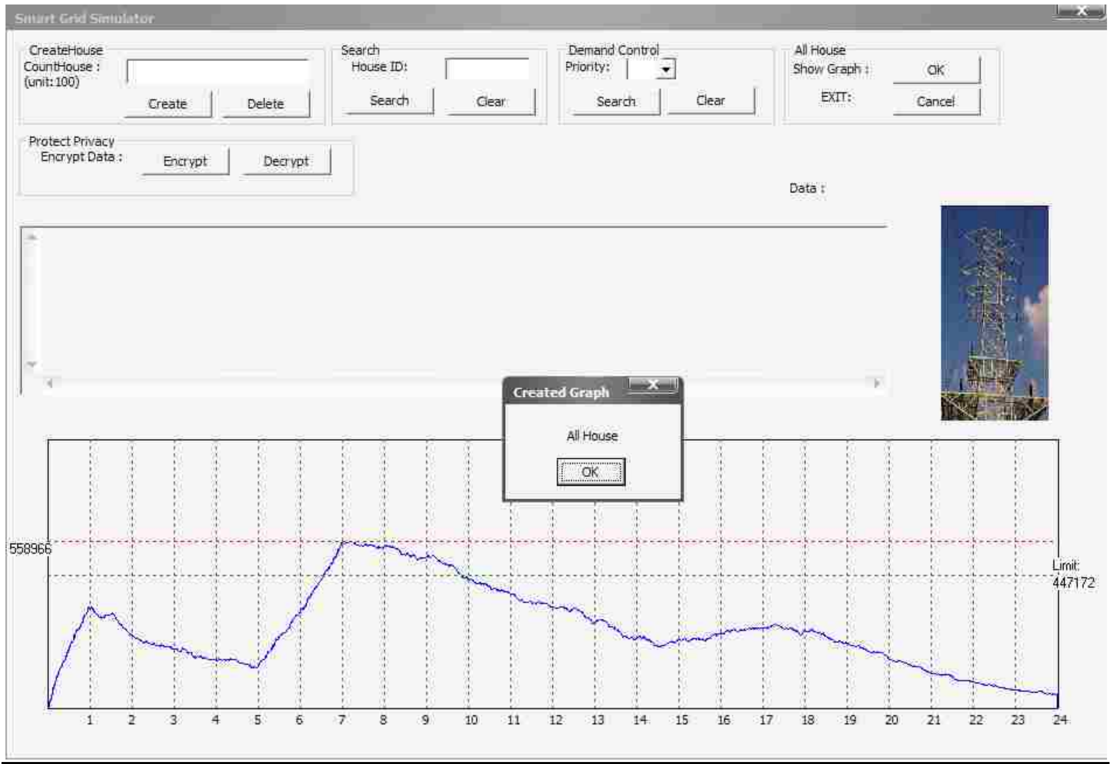


Figure 11 Smart Grid Simulator (All House Graph)

A green line implies utmost amount of electric power, 447,172 W, which can be produced by electric company within a day. A red line denotes maximum usage amount of electricity, 558,966 W, which can be consumed by total number of houses within a day. As presented on Figure 11, uppermost peakTime is from 7 AM to 9 AM. Also, from 6:30 AM to 10 AM, is a time period of actual electricity usage being more than estimated electric power usage. Such condition can lead to a blackout. There are two main ways to prevent the outage for happening: Either Electric providers need to generate more electricity in order to meet the needs of consumers or suggest an alternative plan for reducing usage of electric power.

CHAPTER 4

POWER DEMAND CONTROL ANALYSIS

The current Outage Management System (OMS) has functions of estimating electric power usage amount of consumers, producing an additional electric power, and acquiring electricity elsewhere [30]. Since estimating the power usage accurately is almost impossible, the current system not only involves in high cost for supplementing shortage on electricity but also may be problematic when used in certain places like cities experiencing drastic weather change. Therefore, this study plans on suggesting better ways to manage OMS with increased efficiency to a large extent.

4.1 Previous & Current Outage Management systems

Instantly increasing the volume of supplied electric power can be a counter plan on preventing an outage. Yet, it is almost impossible for electricity provider to create such a volume immediately at the moment it is required. The start-up time of power plants varies depending on the type of fuel used. For instance, gas-fired power plant has the shortest start-up time, followed by oil-fired power plant. Coal-fired power plant is the moderate, while nuclear power station has the longest start-up time [32] [33].

As noted in Table 10, although nuclear power plants have lowest productions costs yet generally take several days to produce electricity. Coal power stations also take at least several hours to do so [34]. Therefore, these methods are practically impossible to be employed for avoiding a blackout.

Table 10 U.S. Electricity Production Costs and Components [31]

U.S. Electricity Production Costs and Components
1995 - 2010, In 2010 cents per kilowatt-hour

	Total Production Costs				Operations & Maintenance Costs				Fuel Costs			
Year	Coal	Gas	Nuclear	Petroleum	Coal	Gas	Nuclear	Petroleum	Coal	Gas	Nuclear	Petroleum
1995	2.61	3.79	2.72	5.94	0.62	0.72	1.90	1.67	1.99	3.07	0.82	4.27
1996	2.45	4.63	2.51	6.02	0.54	0.71	1.78	1.37	1.91	3.92	0.74	4.65
1997	2.37	4.69	2.60	5.36	0.53	0.68	1.88	1.12	1.84	4.01	0.72	4.24
1998	2.32	4.11	2.44	3.81	0.56	0.61	1.73	0.73	1.76	3.49	0.71	3.08
1999	2.23	4.45	2.25	4.55	0.53	0.52	1.60	1.02	1.70	3.93	0.65	3.53
2000	2.18	7.37	2.15	6.60	0.52	0.58	1.54	0.82	1.66	6.79	0.61	5.78
2001	2.24	7.41	2.08	6.08	0.55	0.65	1.51	0.82	1.69	6.77	0.57	5.25
2002	2.21	4.70	2.04	5.80	0.56	0.63	1.50	0.94	1.65	4.07	0.54	4.86
2003	2.18	6.49	2.00	6.94	0.56	0.67	1.46	1.09	1.63	5.82	0.54	5.85
2004	2.27	6.49	1.96	6.59	0.58	0.55	1.42	0.97	1.69	5.93	0.53	5.62
2005	2.46	8.12	1.89	9.04	0.58	0.53	1.40	0.97	1.88	7.59	0.50	8.08
2006	2.56	7.01	1.93	10.37	0.60	0.55	1.44	1.36	1.96	6.46	0.50	9.01
2007	2.61	6.77	1.94	10.93	0.61	0.53	1.43	1.46	2.00	6.24	0.50	9.47
2008	2.85	7.95	1.98	17.71	0.61	0.56	1.47	1.91	2.23	7.39	0.51	15.80
2009	3.02	5.07	1.99	13.04	0.69	0.61	1.43	2.69	2.33	4.46	0.56	10.36
2010	3.06	4.86	2.14	15.18	0.70	0.50	1.49	1.98	2.36	4.36	0.65	13.20

Production Costs = Operations and Maintenance Costs + Fuel Costs. Production costs do not include indirect costs and are based on FERC Form 1 filings submitted by regulated utilities. Production costs are modeled for utilities that are not regulated.
Source: Ventyx Velocity Suite
Updated: 5/11

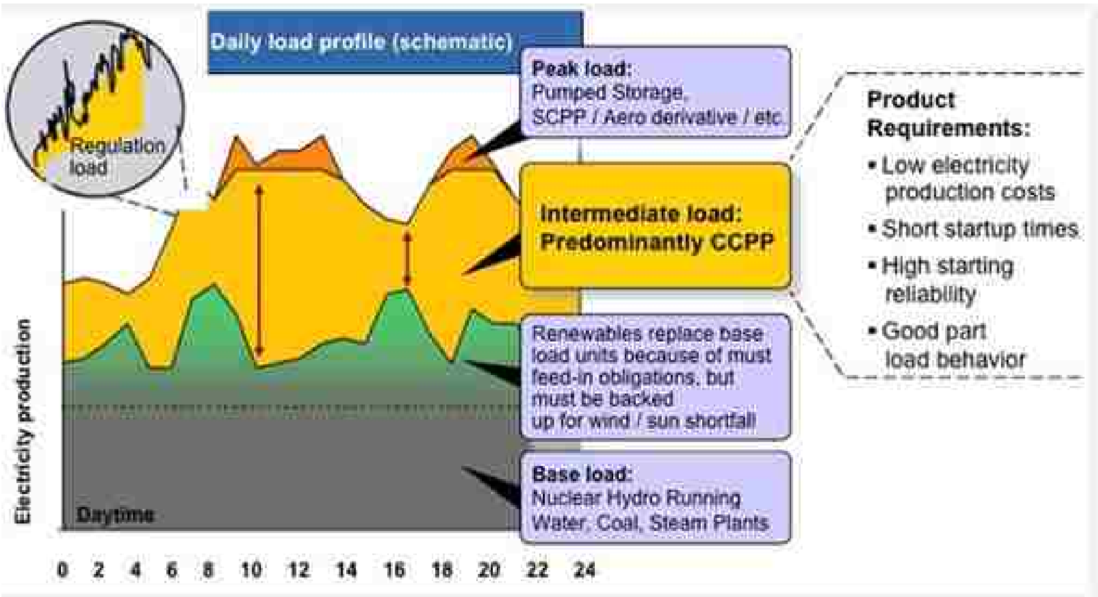


Figure 12 an example of the position played by different technologies to meet daily load requirements [35].

Figure 12 exemplifies a framework of estimating the electric power demand of consumers in real time and generating the power accordingly. Base load in need of definite electricity usage is generally supplied by power plants with relatively low production cost such as nuclear, coal, or renewable energy. CCPP (Combined Cycle Power Plant) works as a main source for intermediate load which tend to have fluctuating electricity usage [36]. Peak load which may experience outage due to difficulty of estimating consumers' demand on electric power utilizes either PSPP (Pumped Storage Power Plant) or SCPP (Simple-Cycle Power Plants). PSPP is a method which utilizes excess amount of electric power to pump water up to the dam [37]. It has limit on the amount of electricity that can be produced. Unlike CCPP with relatively high energy efficiency, approximately 60%, SCPP has the energy efficiency of only 30% to 40% [38]. Although petroleum or gas is ideal to be used in SCPP for supplying peak load as it can promptly operate electric generator, its high production cost limits the practicality to be used. Due to its fluctuating electricity demand, peak load involves additional cost for storing and maintaining electric power or constructing additional electric generator. Therefore, this study attempts to explore ways to increase efficiency of energy and to lower high management cost of current peak load with the use of Smart Grid.

4.2 Outage Management System by Priority Control

OMS which is currently employed in most of power plants and/or electricity provider has major focus on ways of instantly producing a large amount of electric power to meet the needs of consumer or to prevent blackout. Yet, this study suggests different approaches to avoid outage by implementing Smart Grid Simulator within OMS. It enables the amount of electric power usage to be lowered either by turning off unnecessary electrical devicesor by reducing the amount of wasted electricity considerably.

NVEnergy is currently utilizing Advanced Metering Infrastructure(AMI), one of the OMS with Smart Grid control, to control degree of air conditioners all at the same time as a practice for temporarily reducing the electric power usage [39]. Yet, the method has some limitations that need to be improved. Although AMI is employed with consumers' permission, it could cause inconvenience to consumers since it does not accommodate individual preferences of consumers. Since current system does not have a capability to adequately adjust the amount of electricity that need to be reduced, electricity providers ends up reducing excessive amount of electric power than they need to. In other words, they are wasting the electricity that can be sold to consumers. Moreover, NVEnergy is compensating a dollar for each event per consumer whenever AMI is used to adjust degree of all air conditioners in the system. These conditions show that the current OMS costs considerable amount to the electricity provider.

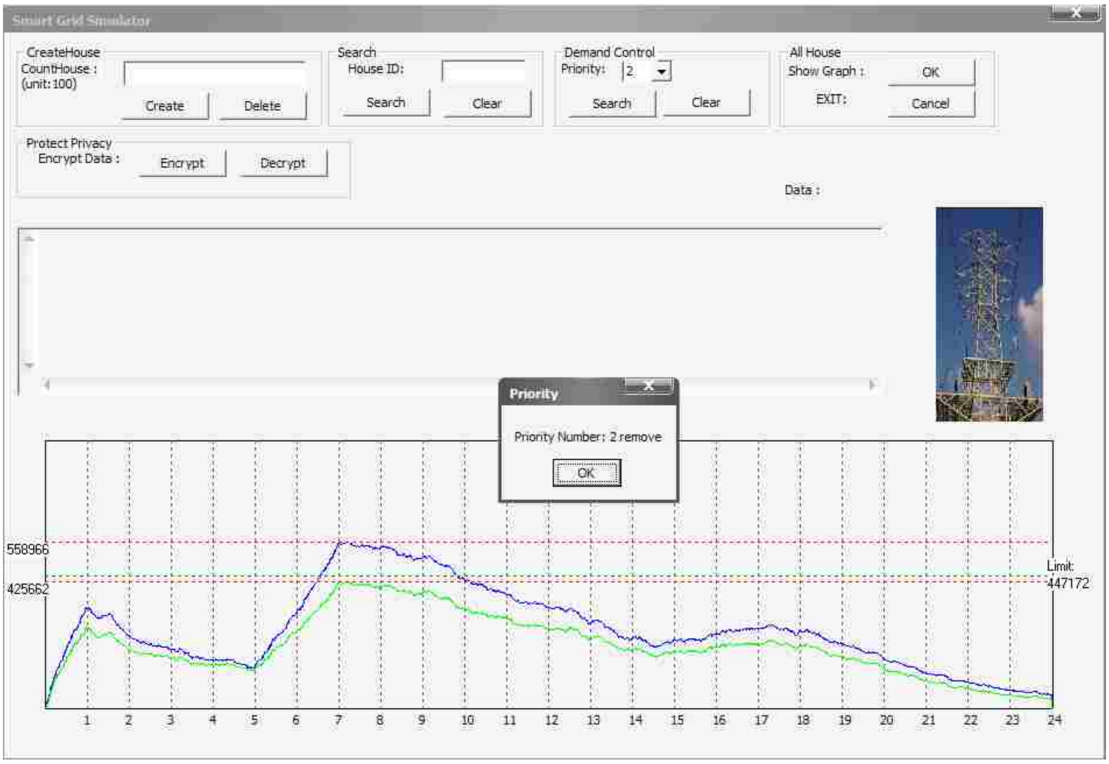
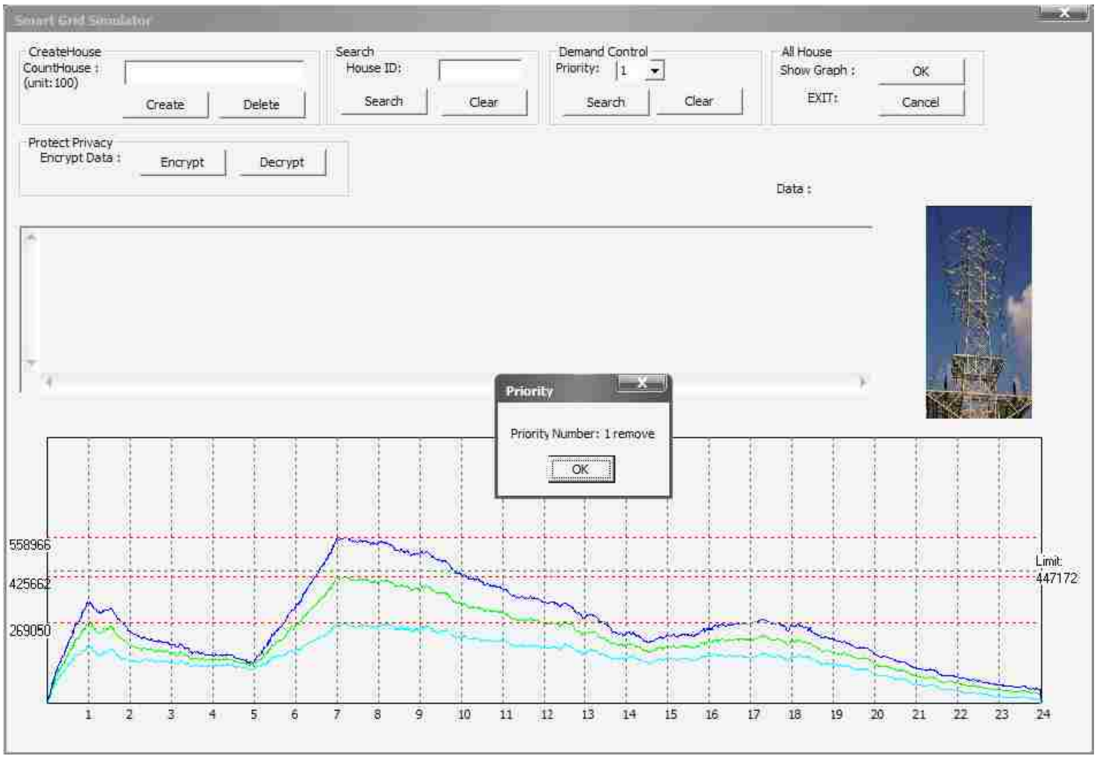


Figure 13 Smart Grid Simulator (Priority 2 removed graph)

By setting priority on electronic devices with the use of Smart Grid Simulator, we plan on solving the problems mentioned above in relation to current OMS: causing inconvenience to customers and financial loss to electricity provider. Unlike the prior method used to reduce the amount of electricity usage all at once, setting a priority can serve consumers better as it enables electricity providers to preferentially control those electrical devices with low level priority set by consumers. Moreover, it can lower the financial loss of electricity provider by reducing only the adequate amount of electricity instead of excessively reducing a large sum of electric power.

Figure 13 proves that producing additional amount of electricity is not necessary as outage can be prevented by simply turning off electronic devices with lowest priority, 2. A light-green graph in Figure 13 stands for the amount of electricity usage reduced with the adjustment of appliances with priority 2. Outage can be prevented as long as the total usage amount of electricity does not exceed 447,172 W, marked as green (middle) line on Figure 13. The electricity provider is able to adjust the maximum usage amount of electric power by simply turning off the electrical devices with priority 2. Since the devices with priority 2 are less of a concern to consumers, controlling power usage of these appliances will not cause major inconveniences to customers. Moreover, electricity providers do not need to produce additional amount of electricity if the total electric power usage can be controlled to 447,172 W. Naturally, there will be certain circumstances that turning off home appliances under priority 2 is not enough for avoiding blackout. In that situation, Smart Grid Simulator can reduce the total electricity usage of consumersby managing the devices of priority 1 or higher.



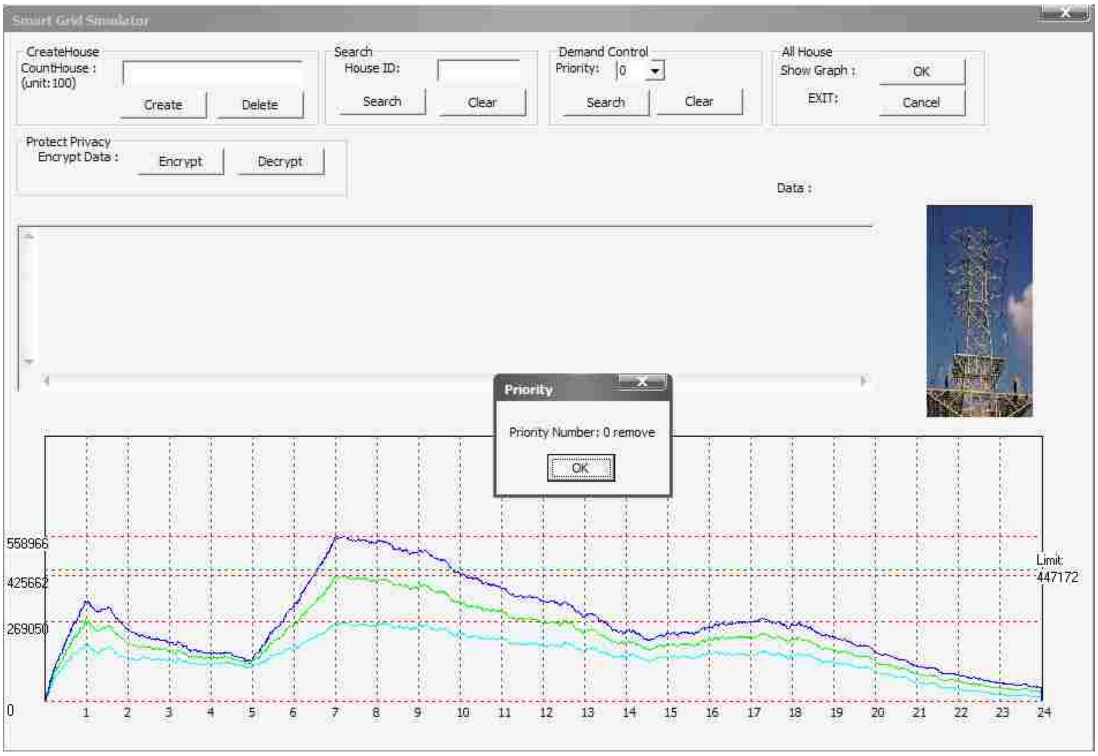


Figure 14 Smart Grid Simulator (removed High priority)

Figure 14 shows how an electricity provider can control electrical devices below priority 1 set by the home owners. The lowest graph shown as sky blue illustrates how much electricity can be reduced by turning off the appliances that are below priority 1. By doing so, electricity providers can lower the electric power usage to 269,050W. Red line which denotes ‘0’ watt shows a condition when all electrical devices are switched off. In other words, this is a case where appliances with priority 0 are turned off in addition to shutting down electric devices with priority 2 and 1.

With the use of Smart Grid Simulator, inconveniences that current OMS brought to consumers can be remarkably reduced as priority was set on various kinds of home appliances according to consumers’ preferences. Moreover, electricity providers can efficiently control electric power usage as they receive detailed information on numerous types of electric devices that consumers use.

CHAPTER 5

PRIVACY PROTECTION IN SMART GRID

There are several undesirable effects stemming from the recent development of Smart Grid technology. One of them is a privacy violation. Home owners who are using Smart Grid technology are at a risk of giving out their personal information unintentionally. For instance, information on various kinds of electric devices including expensive appliances, which are in use of household, will be released to the electricity provider, and potentially to a 3rd party person if the data is mishandled. It may be used as a marketing source for businesses and even can lead to an easier burglary.

Therefore, this study attempts to resolve those issues by implementing Priority Control and encrypting HouseID. Before going in to details of these approaches, two assumptions are constructed for a better understanding. Houses used as data in Smart Grid Simulator already made contracts with electricity providers so that information of electric devices used in the house is allowed to be accessed. Also, the Data Anonymization Server does not try to access such information and is considered to be a trustworthy entity.

5.1 Prior work

Security problems caused by the use of Smart Grid technology were overlooked in the earlier years [40]. Similar awareness goes with privacy matter. Although general interest on Smart Grid has risen substantially, there is little alertness on privacy issues in regards to Smart Grid technology. 2010 was the first year when

NIST finally started paying attention to the privacy aspect as one of subcategories in security group. In order to protect privacy, NIST set guidelines for Smart Grid Cyber Security including privacy, list of weak points on privacy, analysis of potential privacy issues, and so on [41]. Also, Cyber Security Working Group (CSWG) in NIST suggested five-step methodology to develop the Guidelines for cyber security in Smart Grid. The five steps are expressed below [42]:

- First step: selecting cases used Smart Grid in relation to cyber security issues
- Second step: performing analysis of risk on used cases
- Third step: setting guidelines for foundation of security architecture
- Fourth step: explaining high-level security requirements
- Final step: Smart Grid Conformity Testing and Certification

5.2 Violation factor of Privacy in electric power usage

Current AMI used by electricity providers employs high-frequency metering data asa method of getting information from consumers. Although high-frequency metering data is a necessary element for operating the network efficiently, it has a downside effect of revealing consumers' private information such as each house's electricity usage to electricity providers [43]. Similar conditions apply to the Smart Grid Simulator constructed in this study. Since electricity providers are allowed to have a control over home appliances of individual homes to prevent outage, electric power usage data of consumers are bound to be exposed. Even without individual device usage information, it is possible to estimate the devices usage to some degree from the aggregate power consumption. As shown on Figure 15, it is easy to determine certain kinds of electric devices being used in a single house simply by taking a look at the electricity usage pattern.

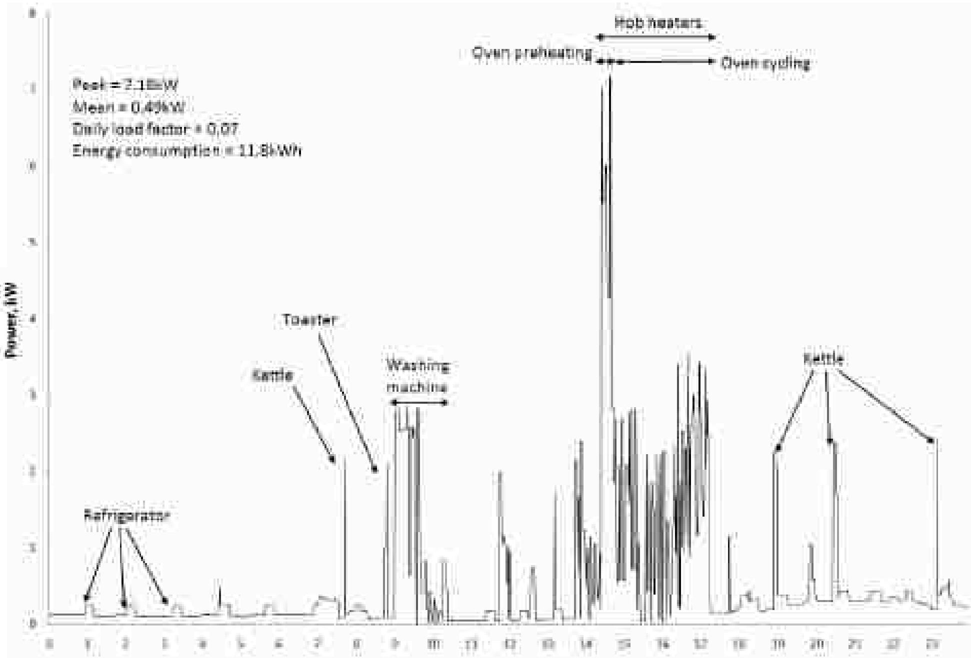


Figure 15 Household electricity demand profile recorded on a one-minute time base, reproduced form [44]

Moreover, electricity demand profile of a household can display various information of the consumer. For instance, it shows the approximate time of house being vacant and makes the house vulnerable to burglary as the profile reveals the time frame for primary amount of electricity as well as minimal electric power being used. It also displays consumers' life patterns such as work schedule, activity hours, and so on. Moreover, by looking at the number of home appliances in use and the frequency of those devices being used throughout the day, the number of household members along with their sex, age, and economic standard can be easily estimated. Such private information can be misused as a marketing tool for businesses. Table 11 comprehensively summarized the potential patterns of privacy violation that may possibly occur with the use of Smart Grid.

Table 11 Patterns of possible privacy violation caused by Smart Grid [45]

Patterns	Contents
Identifying types of individual behavior	Consumer activities and kinds of electric devices can be estimated by electricity usage time and location of appliances being used
Illegal use of individuals' names	A combination of personal information and electric power usage information can be misused for impersonating a service provider.
Perform monitoring in real-time	Owner's information such as whether individuals are in household or what activities they are doing is exposed
Exposure of information on owner's activity through residual data	Activities of former resident or company can be vulnerable to new owners.
Profiling	Profiling consumer in a way that was previously impossible or done with complicated method may be possible.
Censorship of consumer activities	Power company or law enforcement can access or use activities or electric power usage of the residents to determine whether they are appropriate or need to be banned
Information leak when combined with other utility companies' information	Personally identifiable information and much more private activities of individuals may be exposed.
Burglary targeting specific households	The absence of an occupantand the presence of a security alarm can be verified by the meter information.

It is possible to make an educated guess that personal information of consumers can be put to a bad use if exposed. Therefore, finding a way to secure privacy of consumer is an essential element that needs to be accompanied with the use of Smart Grid. Consequently, we utilized Data Anonymization as a method of preventing privacy violation.

5.3 Solution by encrypted House ID using RSA

There are two crucial elements that an electricity provider absolutely requires. They are the instant amount of electricity used approximately in a minute and the total amount of electric power usage in relation to a certain house. Yet, these components do not necessarily need to be used together at the same time. More likely, they need to be individually used depending on the purpose of how it gets implemented. For instance, although electricity providers do not have to know the instant amount of electricity used, they must record total amount of electric power usage with detail information such as HouseID in order to charge a bill to consumer. Also, identifying instant electric power usage in a minute frame is essential to electricity providers for properly lowering usage of electricity while knowing full amount of electric power usage with HouseID is not necessary.

As the elements mentioned above create certain conditions, we decided to utilize Data Anonymization Server (DAS) for solving privacy problem. Figure 16 illustrates how DAS can be utilized.

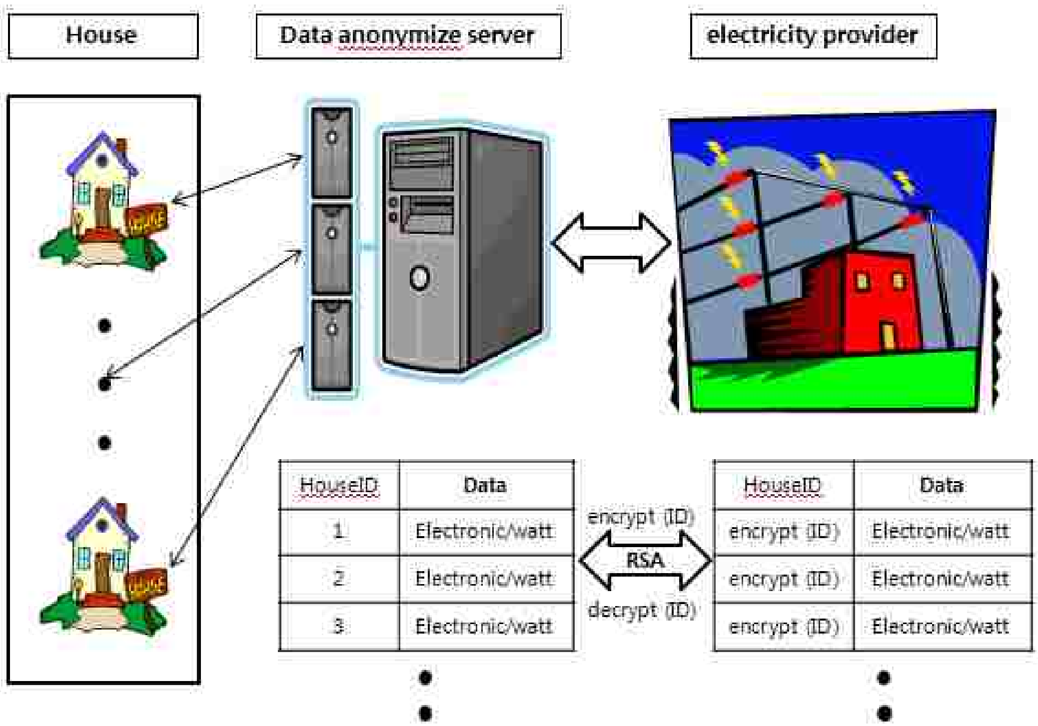


Figure 16 Intercommunication with encrypted HouseID by RSA

As shown onFigure 16, there are four steps involved in applying DAS. At first, each house sends data of electricity usage in each home appliance to DAS. Secondly, DAS partially encrypts HouseID upon receiving data of genTimeFile with the use of Rivest Shamir Adleman (RSA). Then, encrypted data gets delivered to electricity provider. The end product of encrypting genTimeFile using the Simulator was saved as EncryptedDataFile. Since EncryptedDataFile only shows priority, name, and watt of electric devices but not an exact HouseID, electricity providers cannot gather specifics of personal information. Yet, they still can utilize OMS without specific HouseID. Thirdly, Electricity providers send EncryptedDataFile with encrypted HouseID to DAS when they need to make use of OMS for lowering power usage of electric devices. Last of all, after receiving an order of electricity provider, DAS decrypts HouseID in genTimeFile. Then, DAS orders each house to control electric power usage of appliances using decrypted data.

The reason for employing RSA as a method of encrypting HouseID is that WINDOWS API provides RSA function. Furthermore, RSA can be compatible even with improved version of Smart Grid Simulator and successfully secure privacy of consumer [46]. In other words, RSA will be able to secure the privacy of consumers when the simulator becomes a useful tool to individual consumer for controlling electronic devices in the house. The detailed process of HouseID being encrypted with the use of RSA is exemplified from Figure 17-1 to Figure 17-7.

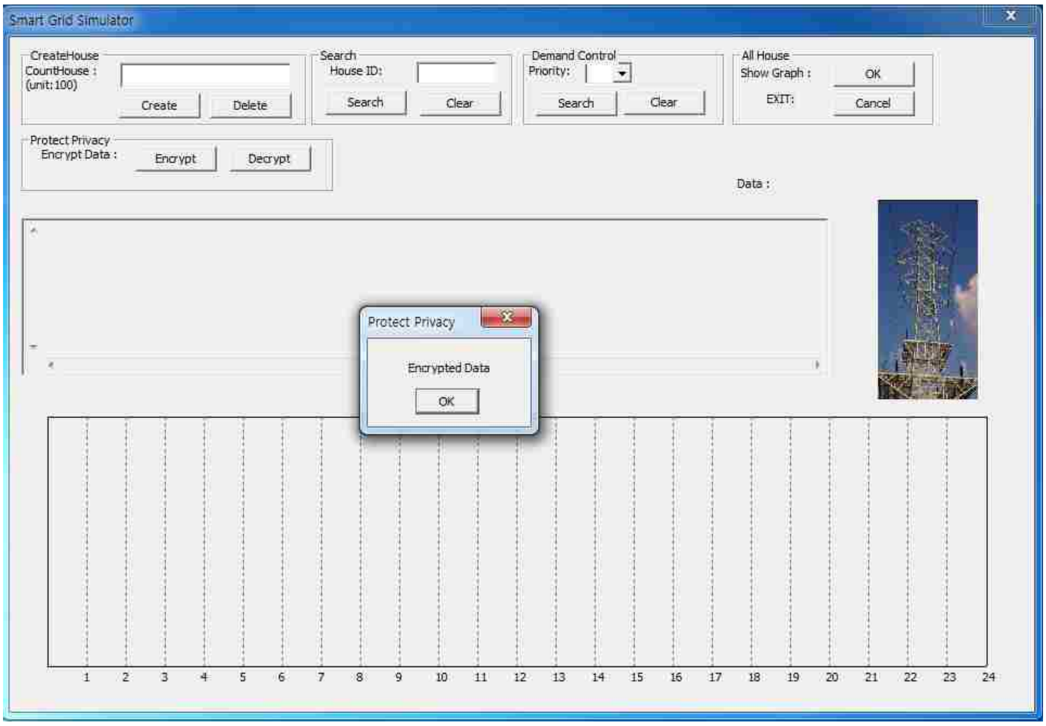


Figure 17-1 Smart Grid Simulator (Encrypted Data)

Figure 17-1 shows that HouseID can be simply encrypted by pressing the Encrypt button in Protect Privacy Box at upper-left corner of Simulator. This function can only be carried out in DAS. As HouseID gets encrypted using RSA, electricity providers will not be able to know which data came from which house.

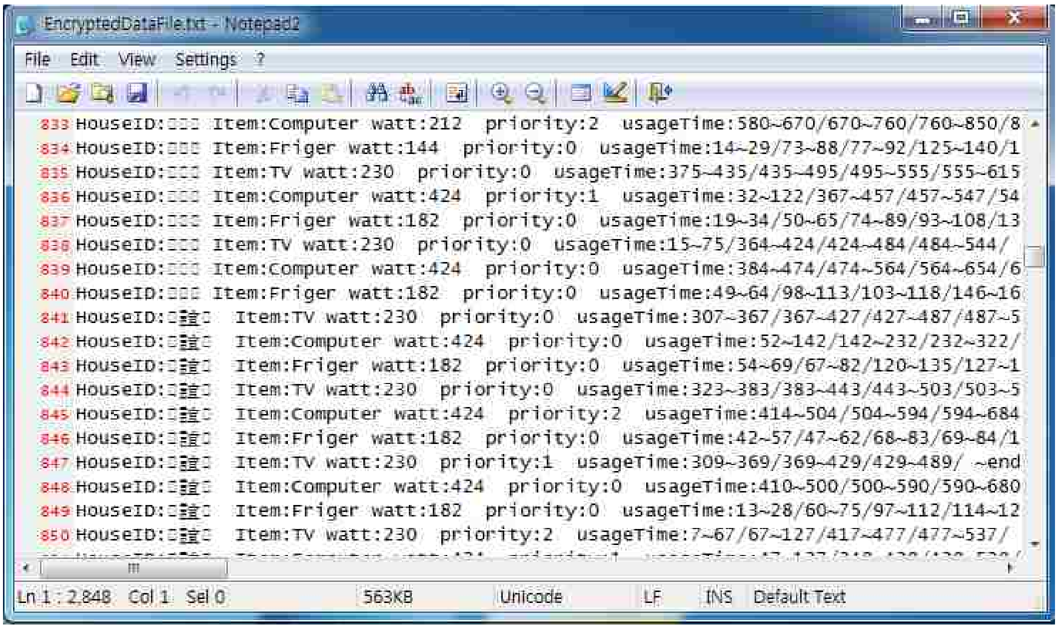


Figure 17-2 Result of encrypt data (EncryptedDataFile)

Figure 17-2 displays how HouseID appears after being encrypted with the use of RSA. Even though HouseID does not reveal its specific number, it still shows other information on home appliances such as name, watt, priority, and usageTime.

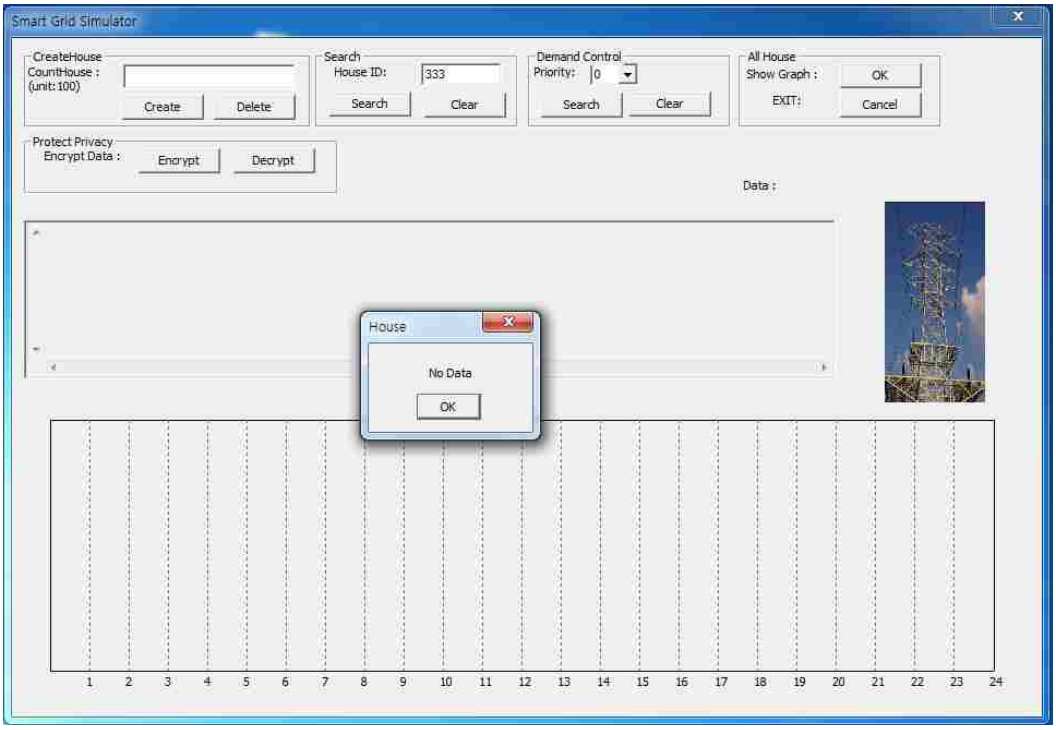


Figure 17-3 Smart Grid Simulator(Search HouseID)

Figure 17-3 implies that it is impossible to locate a certain house after HouseID being encrypted by DAS. When the electricity provider tries to find specific house by putting house number in HouseID box, Smart Grid Simulator doesn’t recognize HouseID and generates a message of “No data”.

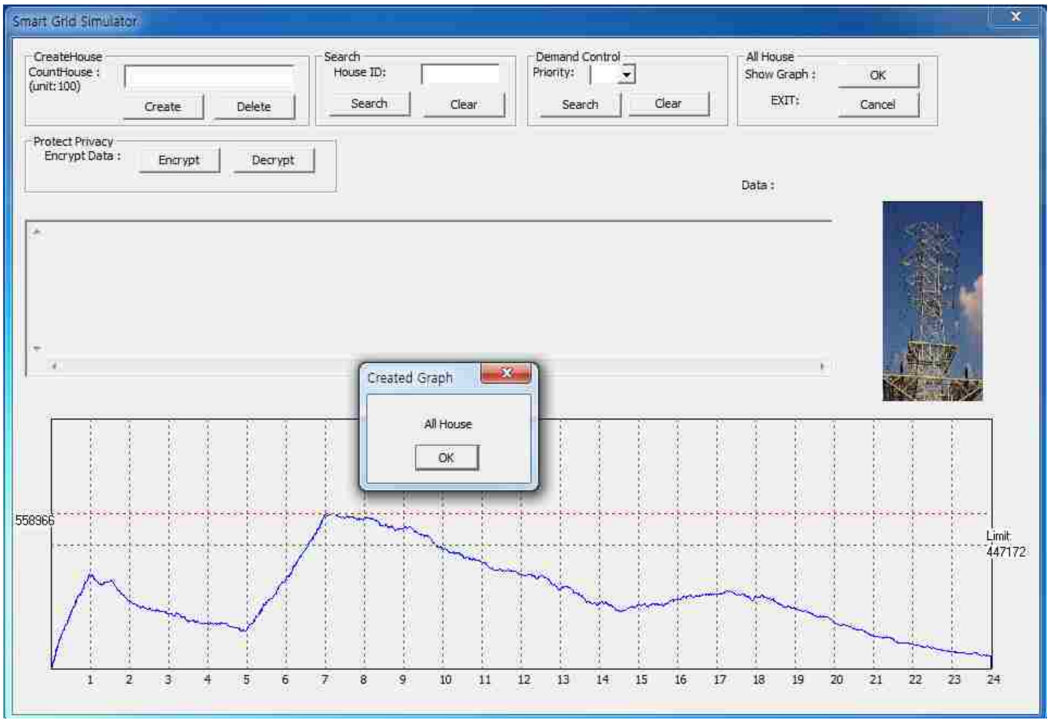


Figure 17-4 Grid Simulator(All House Graph)

Even though electricity providers cannot identify specific house as HouseID is encrypted, they still can access other information such as name, watt, usageTime of electronic devices as shown inFigure 17-2 because EncryptedDataFile contains such sources. Therefore, “All House Graph”, which stands for total usage amount of electric power, can be generated like Figure 17-4.

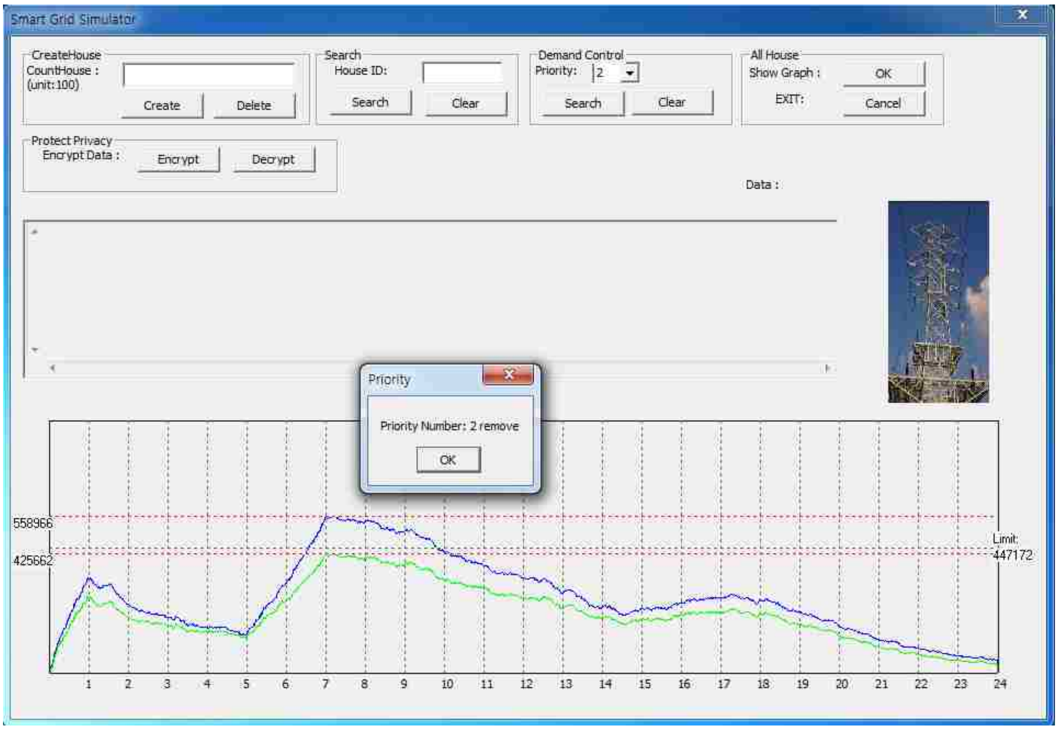


Figure 17-5 Smart Grid Simulator (Priority Control)

Figure 17-5 proves that electricity providers only require priority data for controlling electricity demand of consumers. As an example shown on Figure 17-5, we can see that electricity providers are capable of lowering maximum electric power usage amount of all the houses in the system. Consequently, the example displays that total electricity usage amount of consumers was reduced to 425,662 watts from 558,966 watts.

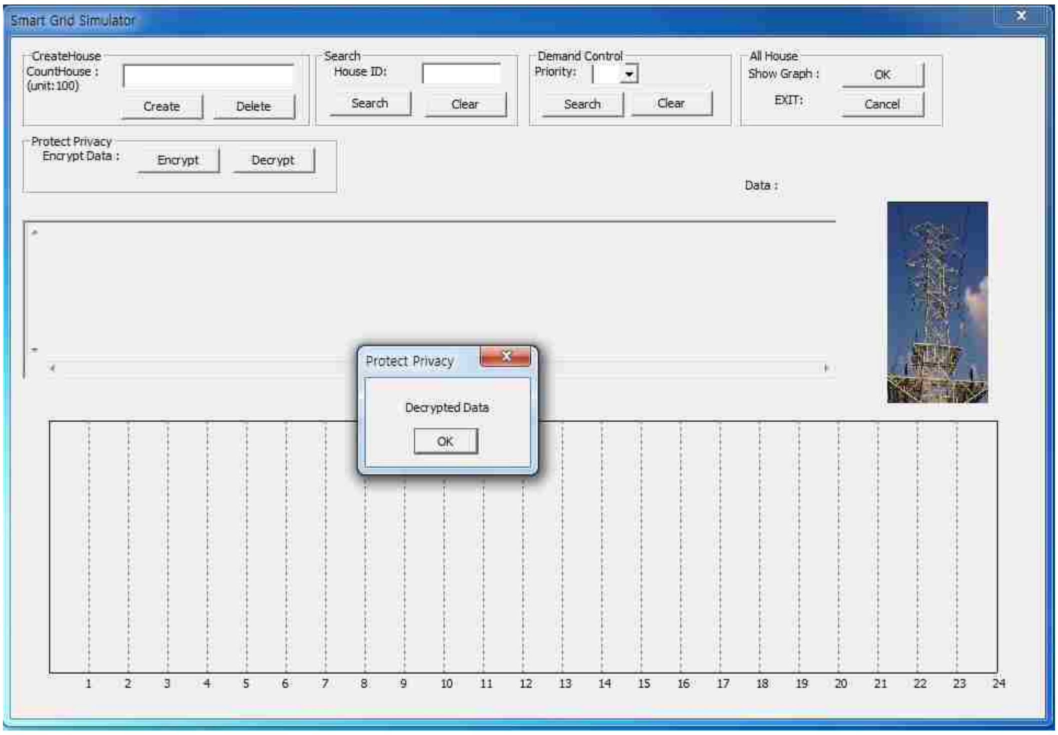


Figure 17-6 Smart Grid Simulator (Decrypted data)

Figure 17-6 shows that HouseIDencrypted by RSA can be decrypted within DAS by clicking the Decrypt button in Protect Privacy Box at upper-left corner of the Simulator. DAS carries out the orders of electricity providers with information stated on decrypted HouseID to households.

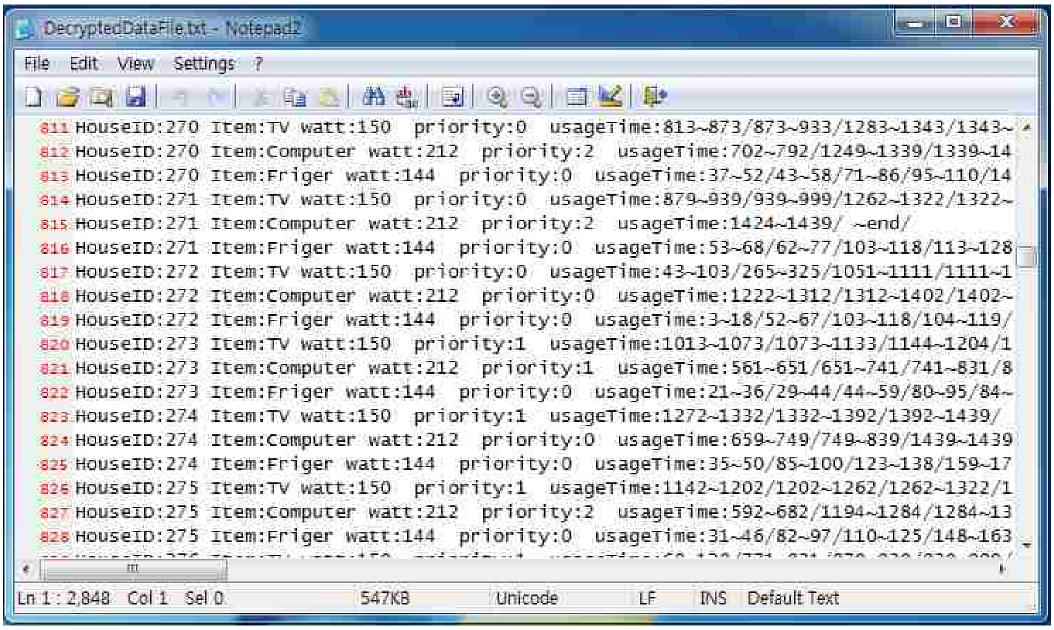


Figure 17-7 Result of decrypt data (DecryptedDataFile)

Figure 17-7 displays the result of executing decryption explained in Figure 17-6. It shows that HouseID has been correctly decrypted from Decrypt function of DAS. By comparing the original contents of genTimeFilein Figure 7 and those of DecryptedDataFile, we can tell they are identical and conclude that Encrypt/Decrypt function works properly in Smart Grid Simulator.

CHATPER 6

CONCLUSION AND FUTURE WORK

Smart Grid has an assortment of potentials that could result in high economical values from lowering additional electric power supply, increasing efficiency of electricity, and reducing environmental pollutant. Consequently, various countries all over the world are putting numerous efforts in standardizing Smart Grid to advance their competitive positions. However, current Smart Grid technology has not been advanced enough to sufficiently support OMS. Therefore, this study attempted to enhance certain functions of Smart Grid by creating Smart Grid Simulator so that OMS can be better utilized to power plants, electricity providers, and consumers. The results of this study clearly show that Smart Grid Simulator creates multiple benefits. For example, it enabled electricity providers to employ priority control to boost the efficiency of current OMS significantly. Also, it facilitates HouseID encryption with the use of RSA for preventing privacy violation.

This study also provides directions for future research on electric devices control. Based on Smart Grid Simulator developed in this study, it is possible to enhance capabilities of consumers further to adjust the characteristics of appliances with their individual preferences. This can be implemented by extending the Search House function and we leave it as a future study. Moreover, further study in Smart Grid can enable electricity providers to provide information on continuously changing cost of electric power to consumers. With such information, consumers can actively adjust their usage amount of electric power if necessary. In return, electricity providers will be able to adequately produce electric power according to consumers' demand.

APPENDIX - Architecture of Smart Grid Simulator(UML)

Figure 18 Generate House Data

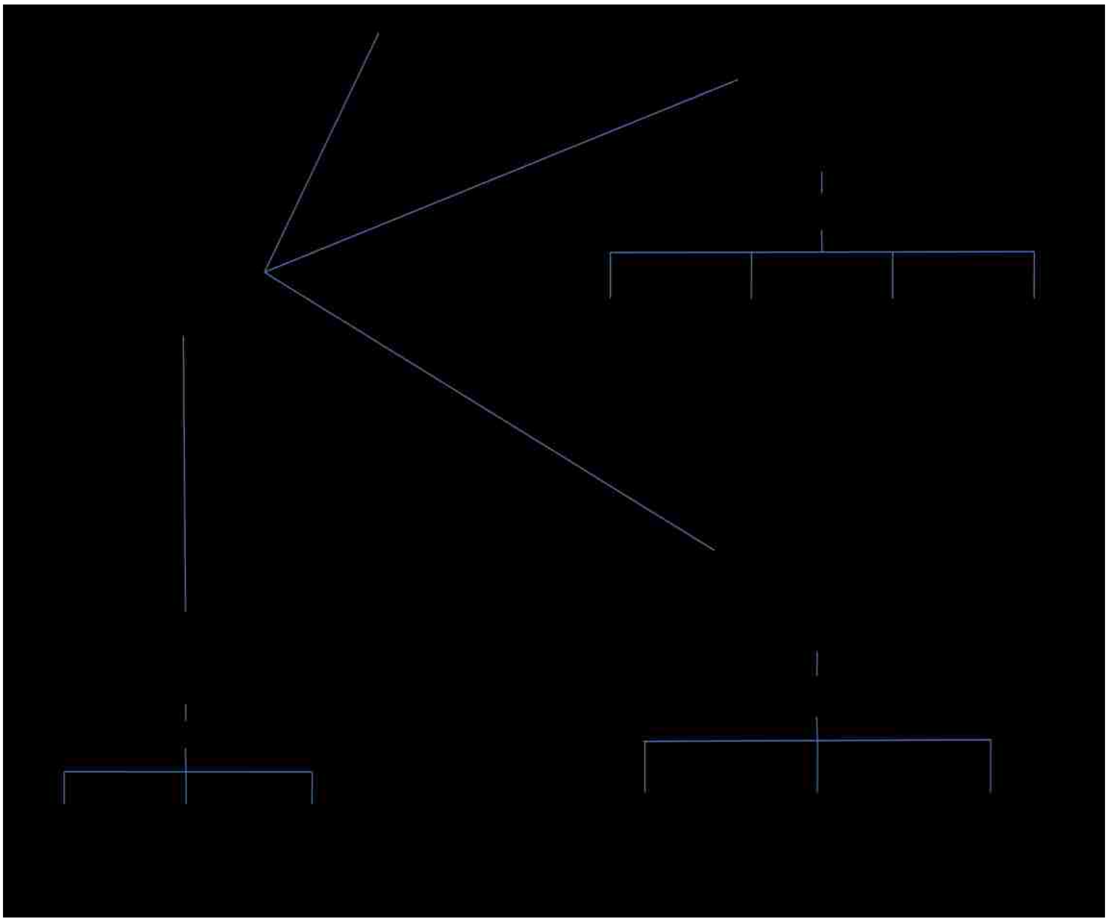


Figure 19 Family type function

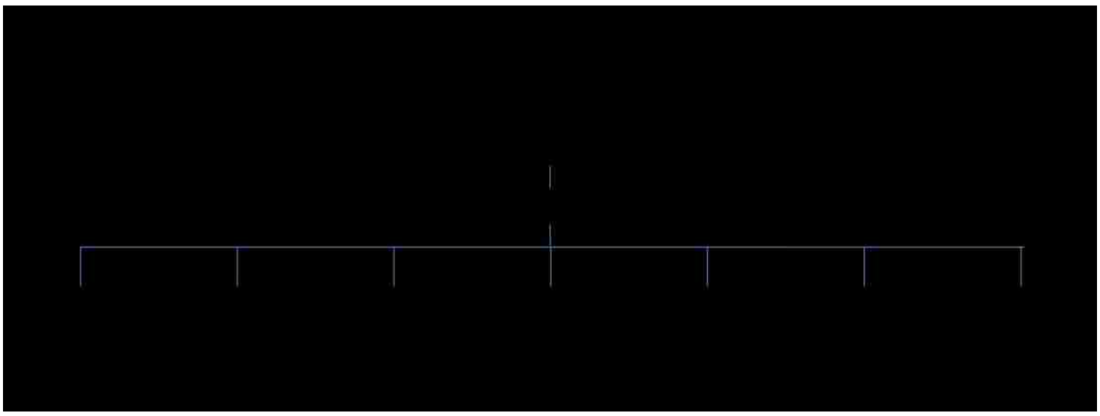


Figure 20 House type function

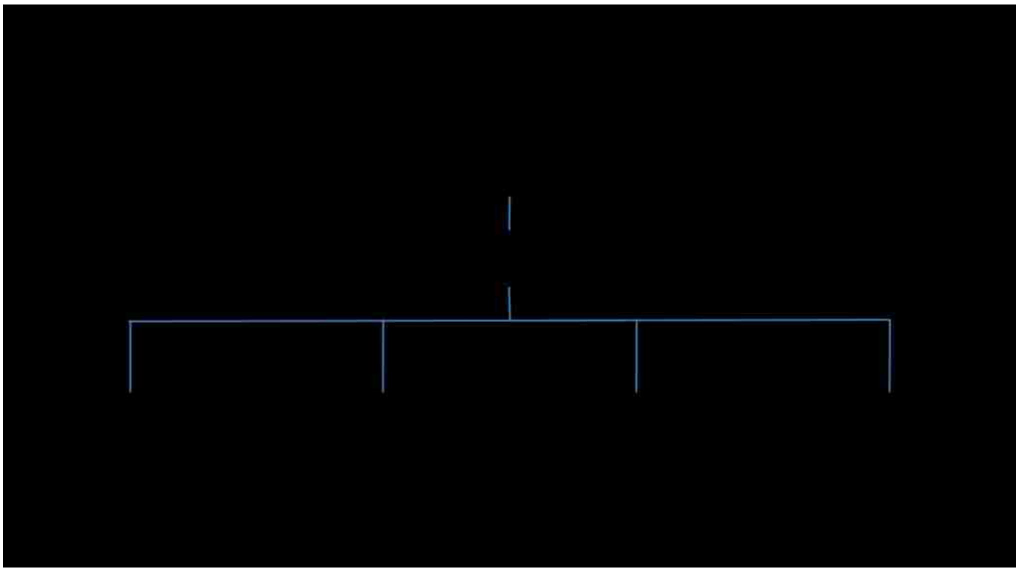


Figure 21 Person type function

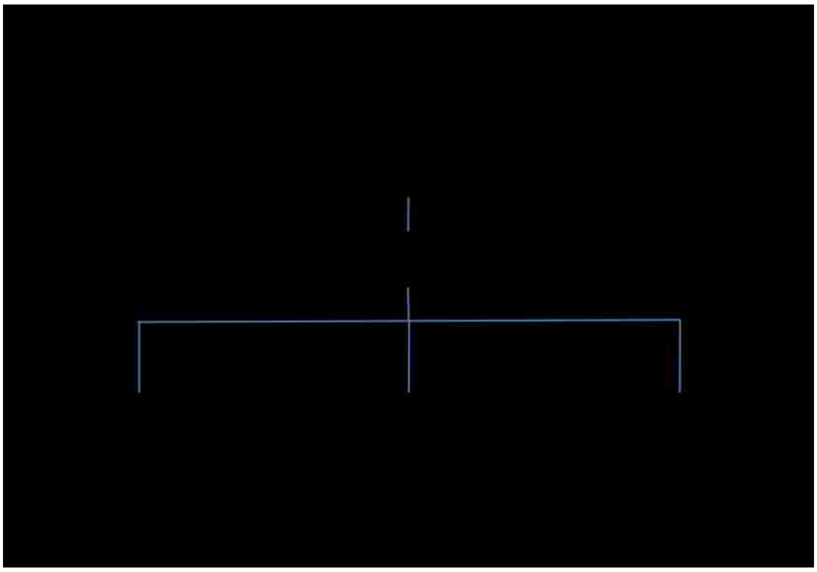


Figure 22 Person type function

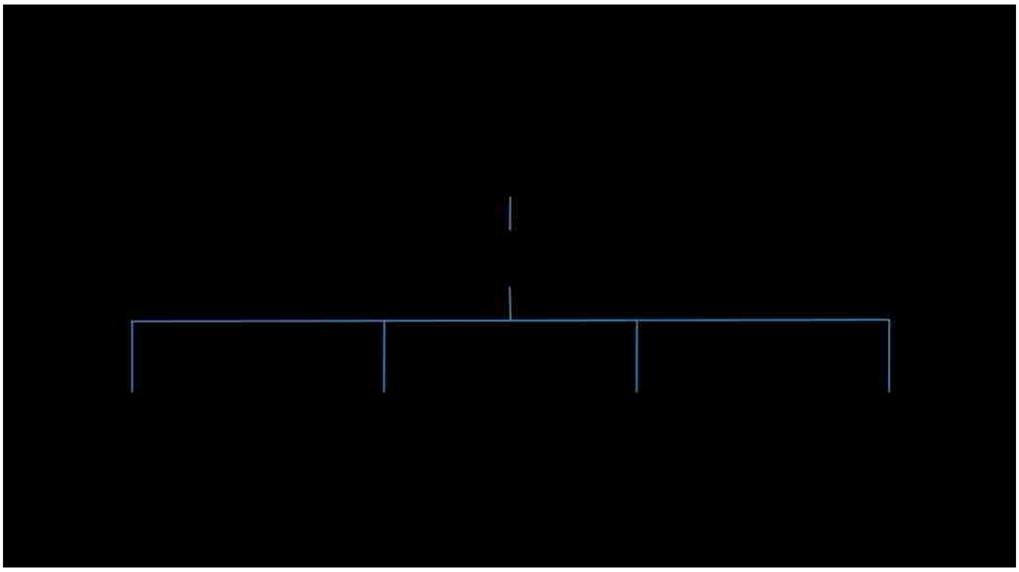


Figure 23 Generator function

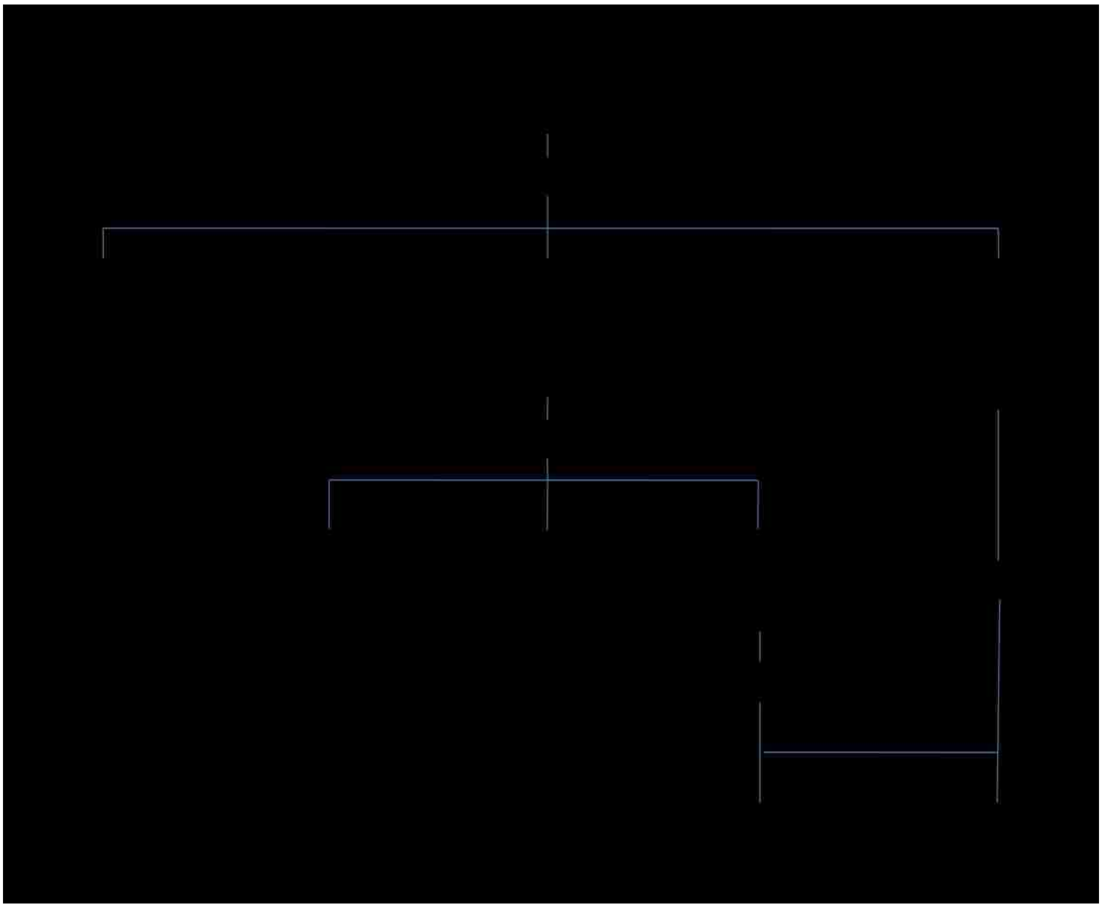


Figure 24 Electronic function

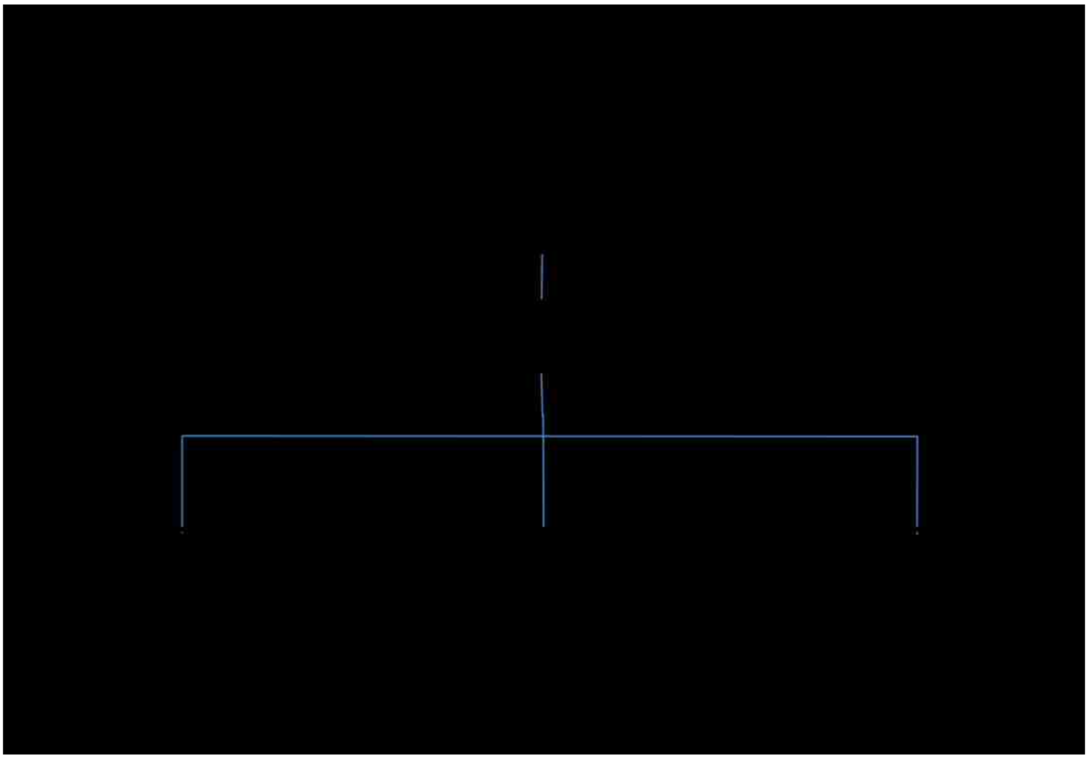


Figure 25 Graph function

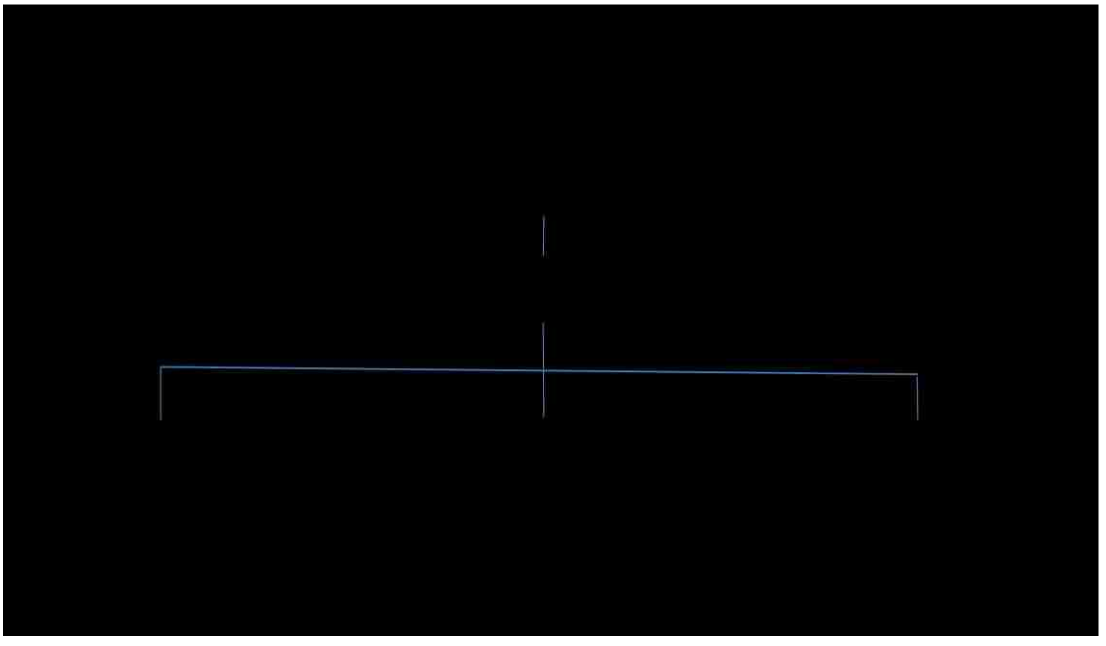
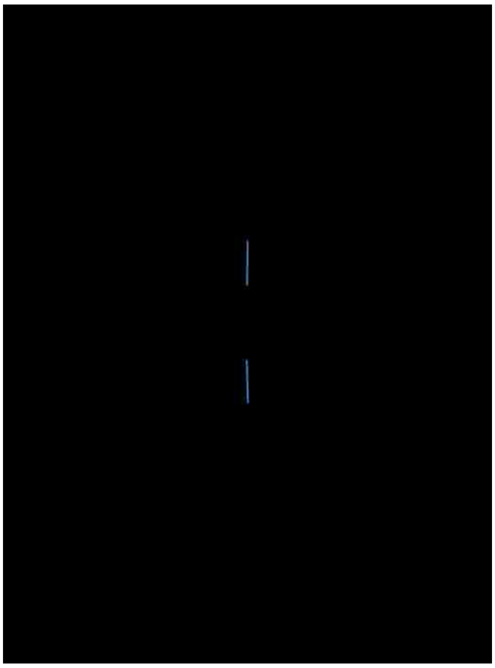


Figure 26 Search function



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