ROLE OF GIS IN RESIDENTIAL MICROGRID

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DECLARATION

I hereby declare that the thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any other university previously.

Monika

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20 June 2016

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SUMMARY

Smart grid is a conventional electric grid with smartness and intelligence added to it, while using communication and IT infrastructure. With the emergence of new technologies smart grid is becoming even more intelligent. Visualization techniques have proven them to be an important tool for adding intelligence to the grid. GIS (Geographical Information System) is a popular visualization technique which holds attention of many researchers and provides wide room for developments in the grid.

In this work, GIS has been used to create a real-time dashboard for displaying/visualizing data from the grid on geographical map. Visualization of grid data on the map helps to optimize the demand curve as the users of the system are able to view their consumption/demand, and can modify it accordingly so as to make efficient use of the available energy. Here a prototype of the system has been created using ArcGIS and QGIS. The data of the grid is collected from the simulation of a small residential microgrid developed in MATLAB/Simulink. Though this prototype has been designed keeping in mind the scenario of Singapore and data is limited to residential microgrid, but the system has ability to perform equally well for any commercial or industrial microgrid across the world. While using GIS, the data floats in the network creating issues of data security and customer privacy. To deal with these security and privacy concerns, a simple data

security system has been proposed, which not only safeguards the critical information of the users of this system but also looks into maintaining privacy of the customers.

The overall system has the objective to optimize the demand curve when data is visualized on geographical map, depending on the schemes and perks made available to the customers, while keeping in mind the concerns of data security and customer privacy.

LIST OF PUBLICATIONS

Few parts of the work done here have already been recognized in one of the topmost conferences of IEEE in the area of smart grid technologies, ISGT (Innovative Smart Grid Technologies) Asia-2015, and another section of the work is under consideration for a journal.

The details of the papers published in ISGT-Asia 2015 include:

1. Monika, Dipti Srinivasan, Thomas Reindl, "GIS as a tool for enhancing the optimization of demand side management in residential microgrid", in proc. of IEEE ISGT Asia 2015 conf.

   Published in Smart Grid Technologies - Asia (ISGT ASIA), 2015 IEEE Innovative
   Date of conference: 3-6 Nov. 2015
   Conference location: Bangkok
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   INSPEC Accession Number: 15722494

2. Monika, Dipti Srinivasan, Thomas Reindl, "Real-Time Display of Data from a Smart-Grid on Geographical Map Using a GIS Tool and its Role in Optimization of Game Theory ", in proc. of ISGT Asia 2015 conf.

   Published in Smart Grid Technologies - Asia (ISGT ASIA), 2015 IEEE Innovative
   Date of conference: 3-6 Nov. 2015
   Conference location: Bangkok
   Print ISBN: 978-1-5090-1237-4
   INSPEC Accession Number:15722539

Another paper has been submitted to journal and is under consideration:

1. Monika, Dipti Srinivasan, Thomas Reindl," Implementation of Data Security while Visualizing Data from Smart Grid Using GIS ", (*article under consideration*)

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CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

1.1.1. SMART GRID

In the context of electrical grid, Smart Grid is becoming a widely used term. It is not an entirely a new feature or entity but is the conventional grid with intelligence added to it. A smart grid is a conventional electric grid of modern times, comprising of communication and IT infrastructure, using electricity with improved efficiency, reliability, and sustainability.

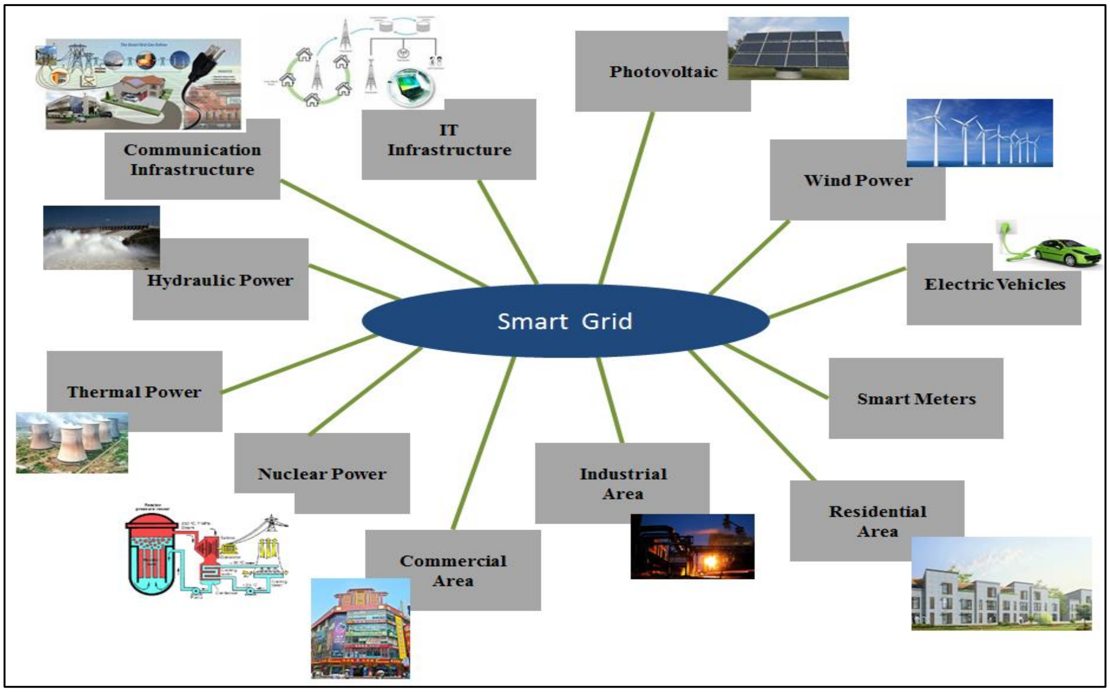


Figure 1.1. Layout of a typical smart grid

When the conventional power grid works in coordination with analog/digital information, IT infrastructure and communication systems, on the same platform, it is known as smart grid. It also features entities like microgrid management software, energy storage devices, smart appliances, distributed energy resources (DERs), smart meters, home energy managers, grid monitoring infrastructure, etc. The prime objective is to automate the electrical grid to the maximum extent possible. [1]- [6] highlight the roadmaps which have aided the process of adding smartness to the grid. Figure 1.1 shows a simple layout for a typical smart grid.

1.1.2. MICROGRID

A microgrid can be considered as a small-scale smart grid, equipped with all features of a modern power grid. In order to satisfy the requirements from hosts, they design and create a combination of local energy assets, resources, and technologies [7]. They also contain smart loads in addition to the smart devices, communication and IT infrastructure, which have the ability to connect to or disconnect from the main grid autonomously. The typical requirements of microgrids include their grid connecting capabilities, islanding capabilities and secure operations [8]. The grid connecting capabilities include integration of renewable resources in the grid in an efficient manner, optimization for economic operation, and extending support to DER for participating in the energy market. Managing critical/non-critical loads to available generation, support for emergency islanding, efficient and reliable island operations while integrating renewable, and optimized island operation for longevity (fuel, maximizing REs) are included in islanding capabilities. Secure operations include cyber secure communications network and distributed cum resilient architecture [9]. Due to presence of microgrids, the electric grid becomes flexible and efficient. Microgrids are responsible for integration of renewable energy resources (such as solar and wind) and distributed energy resources (like combined heat and power, energy storage, and demand response) into the grid. Use of distributed/localized energy resources further increases the system's efficiency by reducing the energy losses [10]. The role of microgrid is to make full utilization of distributed generation, optimize demand response, accept and maintain intermittent power, reduction in cost of electricity, outage management, improve reliability on resources, enhance security and fault monitoring, increase efficiency of power delivery, improve security of electrical systems, management of consumption of energy, reduction in peak load, etc. [11].

1.1.3. DEMAND SIDE MANAGEMENT

When talking about smart grid, demand side management (DSM) is a widely used terminology. It is a set of interconnected and flexible programs, used for reducing the peak demand for electricity. It eventually leads to adding various benefits to the system like reduction in number of blackouts, improved system reliability, mitigation of electrical emergencies, reduction in electricity prices, reduction in harmful emissions to the environment, improved market, ameliorating network issues, etc. DSM has been driven by various motives like cost reduction, environmental concerns, improvement in system reliability, reduction in network issues, etc. [12]. Figure 1.2 shows the main components associated with demand side management.

Demand Response (DR) is the modification done in the consumption of electricity/power in accordance with the supply or available energy. The users tend to shift the consumption at peak demand hours to low demand hours in response to some incentives [13] as shown in figure 1.3.

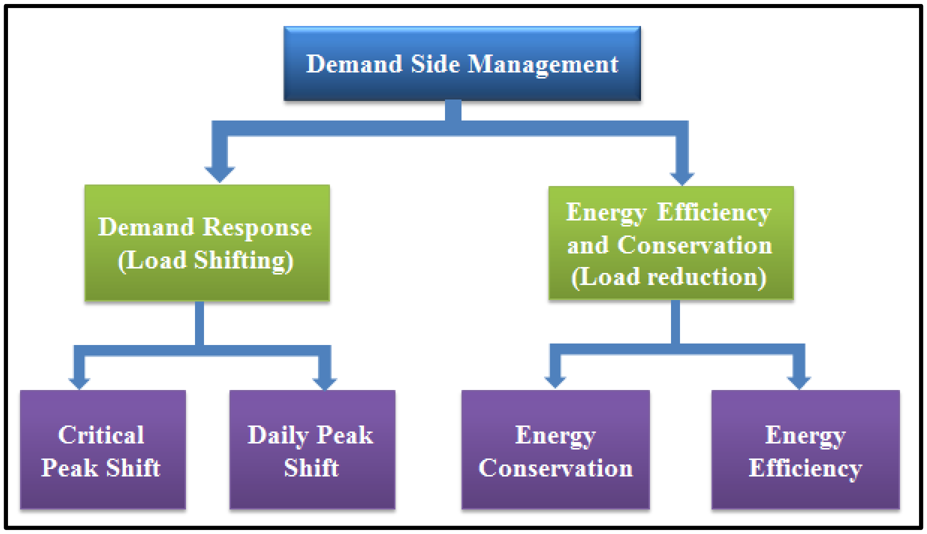


Figure 1.2. Demand Side Management hierarchy

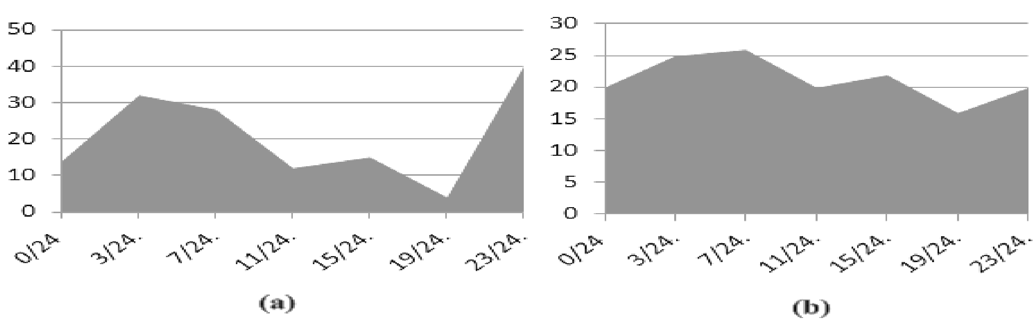
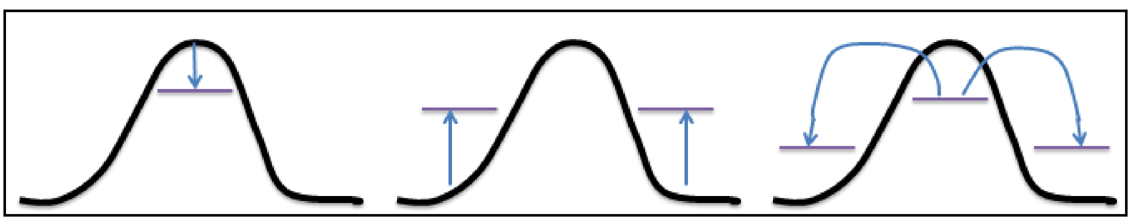


Figure 1.3. Demand response curve

Demand response makes the customers play a significant role in functioning of the power grid. It is also used by planners and operators of electric system to bring coordination between supply and demand [14]. The customers are given incentives for shifting their electricity usage during peak hours like critical peak pricing, real-time pricing, critical peak rebates, variable peak pricing, etc. Eventually, DR leads to accelerate competition in the market by encouraging consumers to reduce their electricity demand and utilities to come up with better deals for consumers to persuade them for contributing to demand side management. It offers various advantages like reduction in wholesale electricity prices; reduce peaks in energy consumption, improvement in system reliability, etc. [15].There are various controls responsible for successful implementation of demand side management like electricity tariffs, incentives available for customers, customer education, customer feedback, controls by utilities, and access to real-time information, etc. The utilities tailor various schemes for electricity pricing depending on the consumption behavior, amount of electricity consumed, demand during on-peak and off-peak hours, etc. For example, flat rate (same rate round the clock), critical peak pricing (extremely high rates during on-peak hours), time of use (defined variable rates for certain blocks of the day), real-time pricing (pricing based on instantaneous demand), and inverted block pricing (higher rates for consumers who have high demands). For encouraging the customers to participate in these schemes, they are offered with exciting incentives. For example, certain free units of energy for cutting down a portion of consumption, low-priced hours of consumption during late hours, etc. Availability of information in real-time environment attracts customers' attention and coerces them for managing their demand response curve. Usage of equipment like home energy controllers, smart meters, programmable communicating thermostats, etc. enables the customers themselves to manage their demand without the involvement of the utilities. This depends on direct load control and automated pricing signal from the utilities [16]. Feedback from the users is another catalyzing factor for the enhancement of DSM in the grid.

Energy management is a critical part of DSM which includes purchasing energy, measurement of performance of devices, developing policies and regulations, conducting audits and surveys, customer awareness, customer education and training, etc. To achieve these targets there are a set of tasks to be performed like collection of data on regular basis and their analysis, procurement of equipment, energy pricing, finding out ways to save energy, creating projects for saving energy, maintenance of communication link among employees, etc. [12]. Apart from energy management other measures include housekeeping, preventive maintenance, buildings regulations, appliance labeling, and energy auditing. Another important aspect of DSM is load management. The load management programs in demand side management include load leveling, load control, and tariff incentives/penalties. Load leveling implies reduction in large fluctuation in the demand curve, which can be achieved either by peak clipping, valley filling or load shifting as shown in figure 1.4. Under the load control measure the utilities remotely switch off the supply to loads assuming that customers have backup electricity supplies like renewable, diesel generators, etc.



(a) (b) (c)

Figure 1.4. Curves showing load leveling using (a) peak clipping, (b) valley filling, (c) load shifting

Though DSM is extremely important for functioning of smart grid, there are challenges while implementing the same. Lack of awareness, reluctance to change in lifestyle, improper energy audits, difficulty in implementing load management programmes, etc. are the challenges to be faced while implementing DSM.

1.1.4. VISUALIZATION TECHNIQUES

The main purpose of the concept of smart grid is adding intelligence to the conventional power grid in addition to incorporating features like service reliability, cost reduction, and improvement in energy efficiency. It is achievable when performance and management of electrical networks is optimized and a comprehensive view of the grid is presented [17]. Visualization techniques are used for this purpose. In the past few decades, a couple of visualization techniques have been developed for visualizing information [18]-[22] and have wide scope in electric grid as well. The traditional methods for visualization include real-time 2D bar chart, single-line diagram, and 3D surface with contour. The multivariable high dimensional visualization techniques include scatter diagram, parallel coordinate, and Andrew curve [23]. Inspite of presence of these techniques, geographical visualization is becoming more popular in smart grid for visualizing the information/data. GIS (Geographical Information System) is a computer-based system, which is used to capture, store, check, and display data/information (in this case, from the grid) on the geographical map [24]. It provides a platform to monitor health of a system (and its components) and display the data on the map in real-time environment [25]. GIS is considered to be a breakthrough technology in the area of smart grid. Utilities use GIS network models for monitoring the grid and doing an analysis of various parameters present in it. It aids the smart grid by optimizing the electric line routing, load forecasting, finding suitable sites for installing grid equipment (like substations, feeders, poles, etc.), estimating costs, analyzing and predicting faults, etc. The insights of the system help to develop statistical relationships between customer attributes and geographical information. GIS can be used for targeted DSM to reduce load on specific circuits as the requirement arises. It also helps the utilities to figure out the customers' activeness and participation in the demand response measures. To achieve this, the information from the grid and the topological data are coded to produce a visual data which can be viewed using the GIS dashboard [26]. GIS comprises of three elements: information to be viewed, computers for storing and processing data, and codes to create the visual form of data [27]. GIS is used to open digital maps on desktops, to create and add new spatial information on the map, to customize the maps as per requirements, etc. According to ESRI, it helps utilities to understand relationship between entities of the grid, eventually determining the risk of failure and control actions to minimize those risks [28] - [29].

There are two types of GIS packages available for the users: commercial (or enterprise GIS) and open source GIS. Both of them are widely used by researchers, having their own advantages and disadvantages. Though researchers nowadays are working with open source GIS, but in the past enterprise GIS had been the main tool used in the area of smart grid. Undoubtedly, GIS has been a transformational tool, when it comes to visualization of pool of data in a systematic matter on the geographical map. In the process of development of new applications and addition of capabilities to the system, GIS is emerging as enterprise-class technology [29]. This gives enormous opportunity for development to private as well as pubic industries. Enterprise GIS, as the name suggests, provides a platform for free flow of data/information (geospatial) across an organization so that large number of users can share the data and contribute into its management. In short it helps in adding business intelligence to the management. It is used for spatial data management, routing, geocoding, map rendering, spatial calculations, etc. An enterprise GIS is expected to be scalable, extensible, reliable, secure, standards-based, capable of delivering high ROI (return on investment), interoperable and so on [29]. Though the enterprise GIS has various advantages like data sharing, collaboration of tools and applications, accurate information to customers and clients regarding products, etc., but 95% of the problems of enterprise GIS are related to cumbersome license protection. Also, the users have to buy the package, which is overpriced. Enterprise GIS is expensive, does not allow import of layers externally, involves licensing, requires high maintenance and is not too much user-friendly (meant for specialists). Open source GIS, as the name suggests is available free of cost to all users and open for modifications in the source code. They are typically worked on by a community of programmers, who volunteer for a project. It works on various programming languages like C/C++, Java, Python, Android, etc. and can operate on both Windows and Linux. It can be used by people on regular basis and is not meant only for GIS specialists. It is user-friendly and extremely flexible. Examples of such software include QGIS, GRASS GIS, SAGA GIS, etc.

1.2. MOTIVATION AND RESEARCH GAP

The first subject that arises while using the GIS system is the need of this system. The data from the grid is made available by using SCADA or DMS. For the purpose of visualization, this data needs to be displayed on the map. To display the data from the grid on the map, and to send back the feedback to the grid, the system of GIS is needed. It acts as a bridge between the grid data and the representation of geospatial data on the map as shown in figure 1.5.

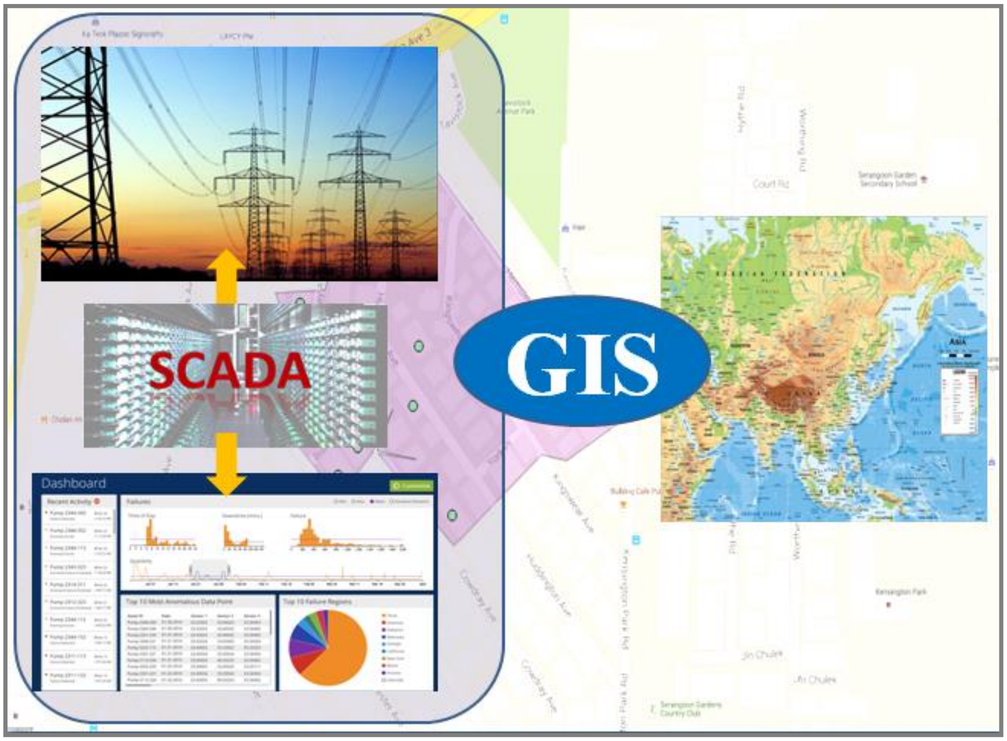


Figure 1.5. Connection between electrical grid and geographical map using GIS

It is a known fact that optimization of any system becomes prominent with visualization. A lot of researches are being carried in the field of smart grid technologies, but their implementation and acceptance by people is still quite slow, as most of them are either not aware of the systems or they do not realize the amount of benefits they would get by adopting the system. GIS proves itself to be useful for doing this job. It helps to portray a real-time image of the grid in front of users, where they can visualize their electricity demand, usage pattern, energy availability, trends in consumption pattern, perks available with variation in electricity usage and so on. This creates awareness among the users and owing to change in their habits it eventually leads to optimization of the demand curve and energy usage.

Though a lot of work has been done by researchers for visualizing information of the grid using GIS, most of them are limited to solar potential mapping, forecasting or cost calculation. As discussed in the next chapter, be it Solar Boston map, or Berkeley Solar map and calculator, or IMBY tool, or Cambridge solar map, all have the main point of focus as solar potential. There are other areas of the grid which remain untouched while the focus lies on photovoltaic. In addition to mapping solar potential, GIS can be used for visualization of other types of information from the grid like demand response, EV parking, fault history and forecasting, energy levels of nanogrids/microgrids, tentative actions to be taken by the users, and so on.

Another important aspect is the use of type of software. In most of the cases, the enterprise/proprietary GIS have been used. Though TERI has recently started working with open-source GIS, but still the focus lies on solar potential calculation. During the course of this research, various aspects of enterprise and open-source GIS were investigated and it was found that ArcGIS has certain limitations which can be overcome by using open-source GIS or a hybrid of enterprise and open-source GIS.

1.3. APPROACH

Here a real-time dashboard has been developed, for displaying information from the grid on the geographical map. This system is based on the 3-tier architecture of GIS system. The three tiers of operation include the business tier, data tier and presentation tier. The business tier is used for creation of layers and shapefiles, writing the operational code, defining the protocols, etc. It forms the backend of the system where all the architecture and creation work goes on. The data tier comprises of database management system and the server which stores the data. The data coming from the field (through SCADA or DMS) is stored in this tier. Also the layers created in GIS can be stored here in the form of shapefiles. The function of storage optimization and data modeling is performed in this tier. The presentation tier is used for displaying the data/information on geographical map for visualization. It provides a real-time dashboard for displaying the information in the form of layers on the map (which is created in the business tier) as web pages. This layer involves protocols like HTTP, TCP/IP, etc. as the information has HTML components because of the web pages.

1.4. OBJECTIVES AND CONTRIBUTIONS

In this piece of work, the main focus remains on use of GIS for visualizing information from the grid over the geographical map in real-time environment, keeping in mind the concerns of data security and customer privacy. The main aspects to be focused upon while developing the system here include

1. Effective use of GIS for developing a real-time dashboard in order to display the data/information from the grid on the map.
2. Optimization of demand curve contributing to demand side management
3. Looking into aspects of data security and customer privacy while developing this system, in order to earn customer's acceptance and reliability in the system

4. Creating modularity in the system (in the form of layers) for faster operation and execution of commands (downloading desired data from the server onto the map)
5. Development of a simple and user-friendly dashboard which acts as a GUI between the user and the grid

1.5. ORGANIZATION OF THE THESIS

The rest of the thesis is organized as follows: Literature review has been presented in chapter 2, which highlights the role of GIS in smart grid; its need; and also discusses about the relevant work in the area of visualization techniques, GIS with smart grid, GIS with solar energy and data security while using GIS in smart grid. Chapter 3 gives an introduction to the system developed using ArGIS and its ability to operate in a real-time environment. Chapter 4 has a detailed discussion about the system developed using hybrid of Quantum GIS (QGIS) and ArcGIS and its role in optimization of demand curve. Chapter 5 talks about the privacy and security concerns in smart grid and a basic system developed here to solve these issues. Chapter 6 gives an overview of the results of the system and highlights the application of algorithms developed here in other systems. Chapter 7 concludes the work done by the author with the scope of work to be done in future.

CHAPTER 2

LITERATURE REVIEW

Different agencies have their own definition for smart grid. For example, U.S. Department of Energy Microgrid Exchange Group says that microgrid can be defined as a cluster of variable loads (both analog and digital) which are interconnected, and distributed energy resources (DERs). This cluster is an independent controllable entity and has evidently defined electrical boundaries, with the capability of connecting and disconnecting from the grid as and when required. According to CIGRE C6.22 Working Group, smart grid, being an electricity distribution system, comprises of variable electrical loads and DERs, which is operated in a controlled and coordinated way either while connected to the main power network or while being landed [30]. A smart grid possesses various technologies which work together in an integrated fashion to improve the overall performance of the utility. In smart grids, service reliability, reduction in costs and energy efficiency can be improved. This is achievable when utilities are able to optimize the performance and management of the electrical networks, which in turn can be achieved when the view of smart grid is made more comprehensive [31]. The view or visualization helps in providing a comprehensive insight for decision-making. Simple decisions like redirecting power, fault monitoring, deployment of field personnel, etc., which otherwise require a lot of effort, become very easy, once an informative visualization of the system is available.

2.1. ROLE OF GIS IN SMART GRID

Utilities use GIS network models for monitoring the grid and doing an analysis of various parameters of it. It aids the smart grid by optimizing the electric line routing, load forecasting, finding suitable sites for installing grid equipment (like substations, feeders, poles, etc.), estimating costs, analyzing and predicting faults, etc. The insights of the system help to develop statistical relationships between customer attributes and geographical information. GIS can be used for targeted DSM to reduce load on specific circuits. It also helps the utilities to figure out and enhance customers' activeness and participation in the demand response measures. To achieve this, the information from the grid and the topological data are coded to produce a visual data which can be viewed using the GIS dashboard as shown in [32]. GIS has become an important part of the grid. It helps in managing the network model, presenting data/information to the users in appropriate format suiting to their requirement, providing suitable model for the management systems in the grid like SCADA, MDM, DMS, OMS, etc. [33]. A real-time analytic engine is required in the grid for analyzing the network, determining the condition of the systems and its components, and developing forecasting plans. With the use of GIS smart grid becomes even more intelligent, interactive, energy efficient and more projected to the users. GIS is one of the most important visualization techniques which helps in load forecasting, fault analysis, optimization of networks, cost estimation, monitoring the geographical areas, monitoring different parameters of the grid on the map, enhancing communication and coordination among various entities in the grid, and so on. The steps involved in fulfilling these include gathering, managing, mapping and analyzing spatial data [34]. Following these steps leads to creation and addition of new spatial information on the geographical map, which in turn adds various features to the smart grid like data management, situational awareness, workforce automation, planning and analysis. A brief description about role of GIS in smart grid includes [35]:

- Managing data which indicates the health status of utility assets
- Projecting a better and clear depiction of the correlation of network components
- A better understanding of the relationship of the utility assets with their surroundings
- Visualizing the coordination and flow of information among the electrical and communication/IT infrastructure of the grid
- Determining optimal locations for installing the grid components and their better monitoring
- Partial control actions to the grid are made possible (accessible to authorized users)

To summarize, GIS helps in making smart grid even smarter by adding intelligence to it and enabling the utilities to use the combined information (from satellite imagery, GIS, SCADA, DMS, weather systems, etc.) for application varying from inspection/monitoring to maintenance, analysis and planning.

2.2. RELATED WORK

2.2.1. VISUALIZATION TECHNIQUES

Over the last two decades, many visualization techniques have been developed, using which very large and complex data sets can be visualized [36]. A lot of research has been done in the visualization of data in transmission power system. [37]-[41]. Earlier the research was based on low-dimensional techniques such as contour, Green Grid AREVA's Energy Management System (EMS),GDV (graphical data view), and Power World's Simulator [42]-[50]. Works have been done in the field of Geographical Information System (GIS) and multi-dimensional data, by Yixin Cai [51] and Dao Viet Nga [36], where GIS has been used as a method to visualize fault locations in distribution system by means of spatial-temporal dataset.

A lot more can be brought into picture when focus is drawn to the literature in the field of visualization of distributed power system data for past few decades. The literature review shows that with each layer of visualization added, the capabilities of the smart grid increase many folds, adding to the smartness and innovativeness of the grid, making it easy to run, monitor and execute decisions. With the progress of research in this area, the focus has shifted from the traditional visualization techniques (like real-time 2D chart and 3D surface with contour, single line diagram) to multi-dimensional techniques (such as scatter diagram, parallel coordinate and Andrew curve) and GIS techniques (such as spatial analysis and spatial-temporal analysis).

Though research on visualization had been going for years, but during the year 2000, few of them made remarkable contribution to this study. Ivan Herman, in his paper [52], presented a study on graph visualization and navigation techniques, which involves a different perspective for the results of a traditional graph drawing and shows crucial ability of the system to visualize and navigate through the graphs which are potentially large and abstract. In the same year, Thomas J. Overbye, in his papers [53] and [54], discussed about visualization of power system data and new methods for visualization of electric power system information. In [53], there has been discussion about several visualization techniques like contouring of bus and transmission line flow values, techniques for aggregation of data,3D visualization and animation of power system flow values. Using Power World Simulator, these have been used for implementing quite a lot of big scale power systems. The author has also highlighted challenges which include current state of the system, contingency states, and proposed power transactions. In his paper [55], D. A. Keim has talked about data mining on large data sets through information visualization, which lacks 2D and 3D semantics, thereby lacking standard mapping of abstract data onto paper or screen. Keim has addressed the problem of exploration of datasets, which are considered responsible for development of data warehouse systems and database management. In 2002, Keim, in his paper [56], discussed about data visualization and techniques for visual data mining, which is based on information to be visualized, visualization method used, and interaction/distortion system. In [57] M. C. F. de Oliveira has discussed the shift in trend from visualization of information to visual data mining. In [58] – [62] T. J. Overbye has discussed about visualization of various parameters in power systems, its components and how this system can lead to reduction of blackouts and enhancement of power system security. In the next two years he worked on visualization of electric power control center using geographical data views. During the same period ESRI came up with its book [63], acting as a guide for GIS analysts/professionals, geographic modelers, and software engineers. In addition to dynamic feedback agent-based modeling, and simulation modeling, it also discusses about links between various GIS models (presenting a better understanding of applications considering urban, social, health, atmospheric, environmental and economic models) and GIS software. In 2007, P. Compieta came up with his research [64] in spatio-temporal data sets, where a data-mining system has been proposed to deal with huge spatio-temporal data sets. New techniques have been developed to visualize and interpret results. Two such techniques have been highlighted for 3D visualization environments, which are based on Google Earth and Java-3D based tool. They provide advanced interactions with the data set in a non-geo-referenced space. A case study on hurricane Isabel has been discussed in his work. These tools have various advantages, the most important being that they can be understood and used without mastering any query language or underlying structure of data set.

2.2.2. GIS USED IN SMART GRID

The basic idea behind the smart grid is adding intelligence to the grid which includes a better monitoring capability and control. Here GIS proves itself to be an effective tool. GIS ensures timely availability of accurate data to the smart grid for making automated decisions based on accurate information. As in the present scenario, switching decisions of the utility dispatchers are based on human interpretations; hence to avoid human intervention, the smart grid needs a near-perfect GIS model of the electric system to rely upon [65]. Though traditional SCADA systems are early smart grid technologies, but their scope is limited which may include some substations and smart devices (like smart meters or remote controlled disconnect switches). SCADA plays a vital role in collection and management of data, but a real-time analytical engine is needed for analyzing the network, determining the current state of the system, condition monitoring, some degree of prediction of activities in the grid and development of a valid and effective plan. As per ESRI, collaboration of SCADA and such engines helps to attain the cited objectives. Alekhya Datta defines enterprise GIS as a platform for implementation of information technology system in the smart grid resulting in effective integration ability support to smart grid. Enterprise GIS is needed because of the following reasons [66]:

1. Management of customary electric supply, distribution and communication networks
2. Providing comprehensive view of electrical distribution network components and their spatial locations to utility providers and users;
3. Ease in understanding and sharing of data when viewed in geographical context
4. Development of an efficient Smart Electric Grid system by using real-time analytic engines for analyzing present and future conditions.

Though GIS is a transformational technology, it is a relatively new field, which started in the 1970's. Earlier GIS was accessible only by companies and universities, which had expensive computer equipment. But today anyone with a laptop or desktop can use the GIS software. By 2010, the work on Geographic Information System (GIS) in the field of power systems started becoming prominent. As a word processor is used to write documents, a GIS application is used to deal with spatial information on a computer [67]. GIS consists of the geographical data to be viewed (digital data), computers for storage and processing of data and displaying graphics, and computer programs to work with digital data

(GIS application). GIS application can be used for opening digital maps on desktops, creation and addition of new spatial information on the map, creation of printed maps which can be customized as per requirements and performing spatial analysis. Earlier paper maps were used for storing the data in visual form. Then the soft copy of these maps was introduced. But the problem with these was that no changes could be done there. Various works have been done in this area ever since the importance of GIS has been realized. ETAP GIS acts as an interface between the GIS system and Smart Grid Solution. ETAP has the ability of not only displaying maps but also automatically generating electrical one-line diagrams when used with GIS APIs [68]. According to Christine Easterfield of Cambashi Ltd. [69], the future generations have fertile ground for development of systems based on GIS.As per Danny Petrica of Telvent, enterprise GIS is considered to be the most dynamic system feeding the Smart Grid, beginning with Graphic Work Design (GWD) [70]. In [71], there is a discussion about enhanced loss evaluation techniques utilizing interval load data which is collected from Advanced Metering Infrastructure (AMI) system deployed by utilities and detailed system data/information from an available GIS system.

2.2.3. GIS AND SOLAR ENERGY

When talking about the work done in smart grid using GIS, most of them are limited to context of solar energy. Though researches in other fields of smart grid with GIS are in progress but considerable amount of work has been done and implemented in the area of solar energy. [72] – [74] highlight how GIS has been applied to calculate potential rooftop photovoltaic capacity in Boston using the solar map. Solar Boston is a Flex application that showcases active renewable energy installations in Boston. By taking the roof size and shades from surroundings into account, it calculates the rooftop PV capacity and provides rooftop view of the same to users. It uses the proprietary software ArcGIS, provided by ESRI for building digital elevation model (DEM) of the city by burning building heights into building footprints to create a 3-D surface model. A similar system, Berkeley Solar Map, was developed by University of California which makes it possible for the residents and business owners to get an estimate for solar potential of their rooftops, view the existing solar installations, and estimate the system size (based on monthly utility bills) [75] – [77]. It takes into consideration the building's orientation in respect with the sun (accounting the roof factors and/or obstructions) and eventually calculates the probable size and rate for solar electric and hot water systems on any rooftop within the city. The map plots color-coded solar installations throughout the city of Berkeley, which are based on the type of PV installation if it is residential, municipal, commercial or so on. IMBY (In My Back Yard) tool helps one to estimate how much electricity can be produced through solar/wind in the backyard. It also provides generation analysis provided the average system loads for a given location. It is based on Google Maps, and is relatively sophisticated compared to other tools in the same league [78]. In 2013,the researchers at MIT developed a new technique, named Solar System, for predicting the annual yield of any PV array located anywhere on the globe, taking into account local climate, orientation of PV panel, and obstructions from nearby buildings. As a proof of concept, the scientists have created a user-friendly web interface by mapping 17,000 rooftops of Cambridge, [79] – [80]. DONG Energy, which is one of the leading energy groups in Northern Europe, has web applications built with Silverlight and ArcGIS server technology. ArcGIS looks after the visualization and cartographic representation, supporting the process of design and management while Schneider DMS handles the operational aspects [81]. To promote rooftop PV, especially in Indian cities, GIS provides a tool for visual reference in order to investigate locations of interest and perform pre-processed analysis. The Energy Resources Institute (TERI) is currently developing an open-source web-based GIS tool for estimating rooftop solar potential for Indian Solar cities [82].

2.2.4. DATA SECURITY WHILE USING GIS IN SMART GRID

There is another aspect of the grid while visualizing data on the map using GIS, security and privacy issues. In [83], the smart grid communication framework and security layout have been discussed. In addition security analysis has been done mathematically. Smart grid deployments need to adhere to the security requirements like strong authentication techniques [84]. Various works have been done in this field to meet the requirements. In [85] there is a discussion about four concrete protocols, which help in aggregating data securely from the smart meters. In [86], a comparison of methods for authentication of demand response messages has been done. The paper demonstrates that ECDSA (Elliptic Curve Digital Signature Algorithm) offers highest security in contrast with BiBa (Bins and Balls) and HORSE (Hash to Obtain Random Subsets Extension). [87]-[88] explain multiple methods to protect smart meter data privacy. [89]-[90] give a brief explanation of the working of the existing security protocols. There have been initiatives taken by the agencies to implement data security as various levels in the smart grid. Many researchers propose novel methods focusing on the privacy aspect of smart metering data [91]. An efficient and privacy preserving aggregation scheme has been proposed in [92] for securing the information aggregation (using super-increasing sequence) to structure multi-dimensional data and encryption of the structured data by homo-morphed Paillier cryptosystem technique. [93] Proposes a lightweight and privacy preserving scheme which efficiently satisfies the requirements of security and privacy in network on customer side. Various security challenges are being discussed in literature, which include connecting smart meters to hardware devices (like temper-resistance device or electrical batteries) [94]-[96], distorting the consumption value by adding noise to the message at smart meter and removing at control center [97]-[99], and utilizing cryptographic schemes to guarantee information security and customers' privacy [100]-[101].

To sum up, a considerable amount of work has been done with the use of GIS in smart grid in order to make the grid even more intelligent by visualizing the information over the geographical map. A lot of interactive tools have been created by different universities and organizations. These developments have not only contributed to adding smartness to the grid but have also aroused researchers towards working and experimenting with GIS.

CHAPTER 3

REAL-TIME DISPLAY OF DATA ON THE GEOGRAPHICAL MAP

3.1. OBJECTIVE

Here a system has been developed for providing a real-time dashboard to the users, which helps to visualize the data/information from the grid on geographical map. This data may be related to user profiling, energy availability, appliance scheduling, billing, metering, etc. This section provides an insight on the platform being used for visualizing information/data and data modifications, in a real-time environment.

3.2. SYSTEM DESCRIPTION

In this section of the work, a prototype of the system is created, for the scenario of Singapore. To show the ability of the system to work in real-time environment, a prototype of two Singaporean houses has been created on the map. The most basic appliances from a residential microgrid have been considered, which include toaster, food mixer, coffee maker, water heater, fans, computers, air-conditioners, iron, television, microwave oven, lights, refrigerator, vacuum cleaner, boiler, dish-washer and washing machine. As these appliances are used by almost all the households in Singapore, hence they form the sample space for the system developed here. The power ratings for the appliances have been taken from SP (Singapore Power) website and have been mentioned in table 3.1.

The 24-hour consumption data for two houses, with the above mentioned appliances is given in tables 3.2 and 3.3. House 1 is assumed to be 2-room HDB flat and house 2 is assumed to be 4-room HDB flat. It is assumed that house 1 is occupied by a family and house 2 by four students, and the data is considered accordingly. All this data is considered for the scenario of Singapore with the data being collected from EMA and Singapore Power websites.

TABLE 3.1. POWER RATINGS OF THE APPLIANCES

Serial No.	**Appliance**	**Power Rating (in W)**
1.	Washing Machine	500
2.	Dish Washer	1200
3.	Boiler	1100
4.	Vacuum Cleaner	640
5.	Refrigerator	200
6.	Lights	60,100
7.	Microwave Oven	2000
8.	TV	150
9.	Iron	1000
10.	AC	1900
11.	Computer	240
12.	Fan	88
13.	Water Heater	450
14.	Coffee Maker	1100
15.	Food Mixer	130
16.	Toaster	1200

TABLE 3.2. 24-HOUR CONSUMPTION PATTERN FOR HOUSE 1

Appliances/ hour	Washing-machine	Dish-washer	Boiler	Vacuum-cleaner	refrigerator	Light	Microwave-oven	TV	Iron	AC	Computer	Fans	Water-heater	Coffee- maker	Food-mixer	Toaster	Total hourly consumption
1					0.2	0.06				1.9		0.088					2.248
2					0.2	0.06				1.9		0.088					2.248
3					0.2	0.06				1.9		0.088					2.248
4					0.2	0.06				1.9		0.088					2.248
5					0.2	0.06				1.9		0.088					2.248
6					0.2	0.36				1.9		0.088	0.45				2.998
7	0.3		0.44		0.2	0.36	2	0.15	0.5	1.9		0.176	0.45	1.1		1.2	8.776
8	0.2				0.2	0.36		0.15	1	1.9		0.176	0.45		0.13		4.566
9					0.2	0				1.9		0.176					2.276
10					0.2	0				1.9		0.088					2.188
11				0.23	0.2	0				1.9		0.088			0.13		2.548

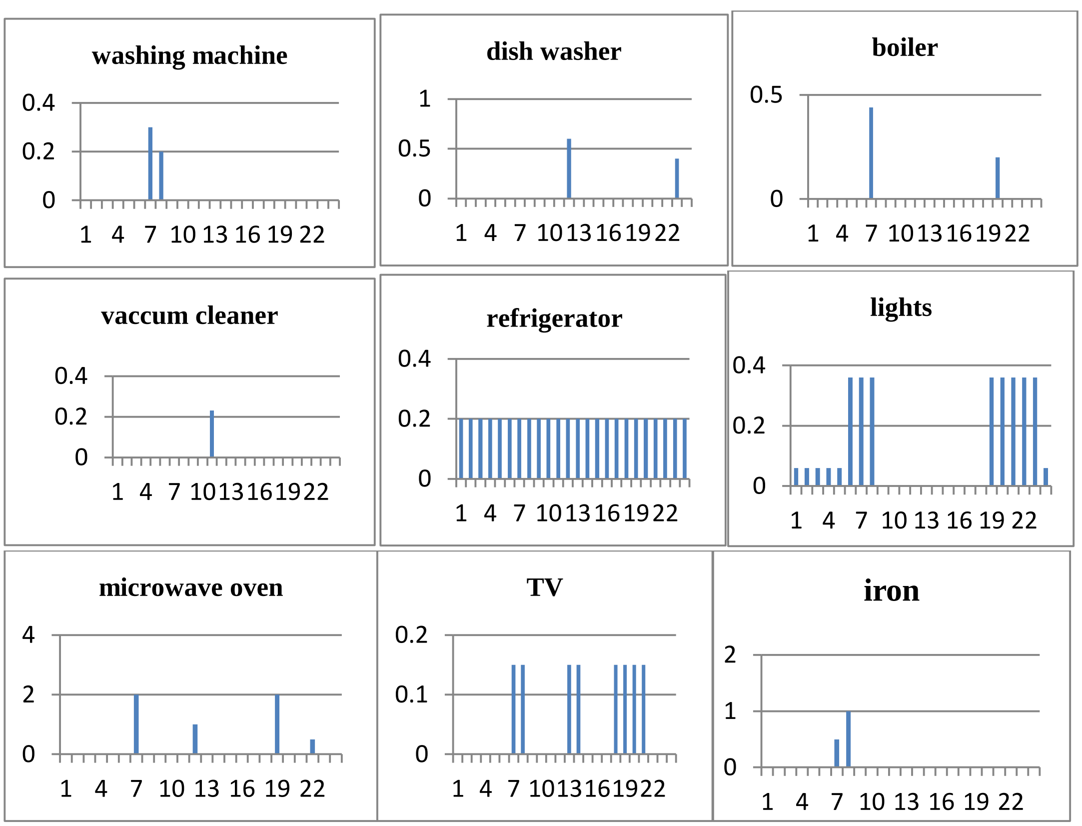
Appliances/ hour	Washing-machine	Dish-washer	Boiler	Vacuum-cleaner	refrigerator	Light	Microwave-oven	TV	Iron	AC	Computer	Fans	Water-heater	Coffee- maker	Food-mixer	Toaster	Total hourly consumption
12		0.6			0.2	0	1			1.9		0.088					3.788
13					0.2	0		0.15		1.9		0.088					2.338
14					0.2	0		0.15		1.9		0.088		1.1			3.438
15					0.2	0				1.9	0.24	0.088					2.428
16					0.2	0				3.8	0.24	0.088					4.328
17					0.2	0				3.8	0.24	0.088					4.328
18					0.2	0		0.15		3.8		0.088					4.238
19					0.2	0.36	2	0.15		3.8		0.176			0.13		6.816
20			0.2		0.2	0.36		0.15		3.8		0.176					4.886
21					0.2	0.36		0.15		3.8		0.176		1.1			5.786
22					0.2	0.36	0.5			3.8	0.24	0.176					5.276
23		0.4			0.2	0.36				1.9	0.24	0.176					3.276
24					0.2	0.06				1.9	0.24	0.176					2.576
total daily consumption	0.5	1	0.64	0.23	4.8	3.24	5.5	1.2	1.5	58.9	1.44	2.904	1.35	3.3	0.39	1.2	88.094

TABLE 3.3. 24-HOUR CONSUMPTION PATTERN FOR HOUSE 2

Appliances/ hour	Washing-machine	Dish-washer	Boiler	Vacuum-cleaner	refrigerator	Light	Microwave-oven	TV	Iron	AC	Computer	Fans	Water-heater	Coffee- maker	Food-mixer	Toaster	Total hourly consumption
1					0.24	0.32				4.9	0.48	0.088					6.028
2					0.24	0.32				4.9	0.48	0.088					6.028
3					0.24	0.32				4.9	0.48	0.088					6.028
4					0.24	0.32				4.9	0.48	0.088					6.028
5					0.24	0.1				4.9		0.088					5.328
6					0.24	0.64				4.9		0.088	0.9				6.768
7	0.5		0.6		0.24	0.64	2	0.15	1.2	4.9		0.176	0.9	1.1		1.2	13.606
8	0.2				0.24	0.64	2	0.15	0.76	4.9		0.176	0.9	0.9	0.13	1.2	12.196
9					0.24	0.64		0.15		4.9		0.176			0.13		6.236
10					0.24	0		0.15		4.9		0.088					5.378
11				0.23	0.24	0			0.24	4.9	0.96	0.088					6.658
12		0.8			0.24	0	1			4.9	0.96	0.088	0.45		0.13		8.568
13					0.24	0	1.25	0.15		4.9	0.96	0.088			0.13		7.718
14					0.24	0		0.15		4.9	0.96	0.088		1.1			7.438
15					0.24	0				4.9	0.96	0.088					6.188
16					0.24	0				7.9	0.96	0.088					9.188
17					0.24	0				7.9	0.72	0.088					8.948

18					0.24	0				7.9	0.24	0.088					8.468
19					0.24	0.64	2	0.15	0.4	7.9	0.24	0.176			0.13		11.876
20			0.3		0.24	0.64		0.15	1.2	7.9	0.24	0.176					10.846
21					0.24	0.64		0.15		7.9	0.24	0.176		1.1			10.446
22					0.24	0.64	0.5	0.15		7.9	0.24	0.176					9.846
23		0.5			0.24	0.64		0.15		4.9	0.24	0.176				1.2	8.046
24					0.24	0.1				4.9	0.24	0.176					5.656
total daily consumption	0.7	1.3	0.9	0.23	5.76	7.24	8.75	1.65	3.8	138.6	10.08	2.904	3.15	4.2	0.65	3.6	193.514

Figure 3.1 shows the consumption pattern for individual appliances of house 1 over a span of 24 hours. Figure 3.2 shows the demand curve (user profile) of house 1 over 24 hours in a given weekday. All measurements are in kWh (represented on the vertical axis in the graphs shown below). Figure 3.3 shows the hourly consumption of the appliances graphically.



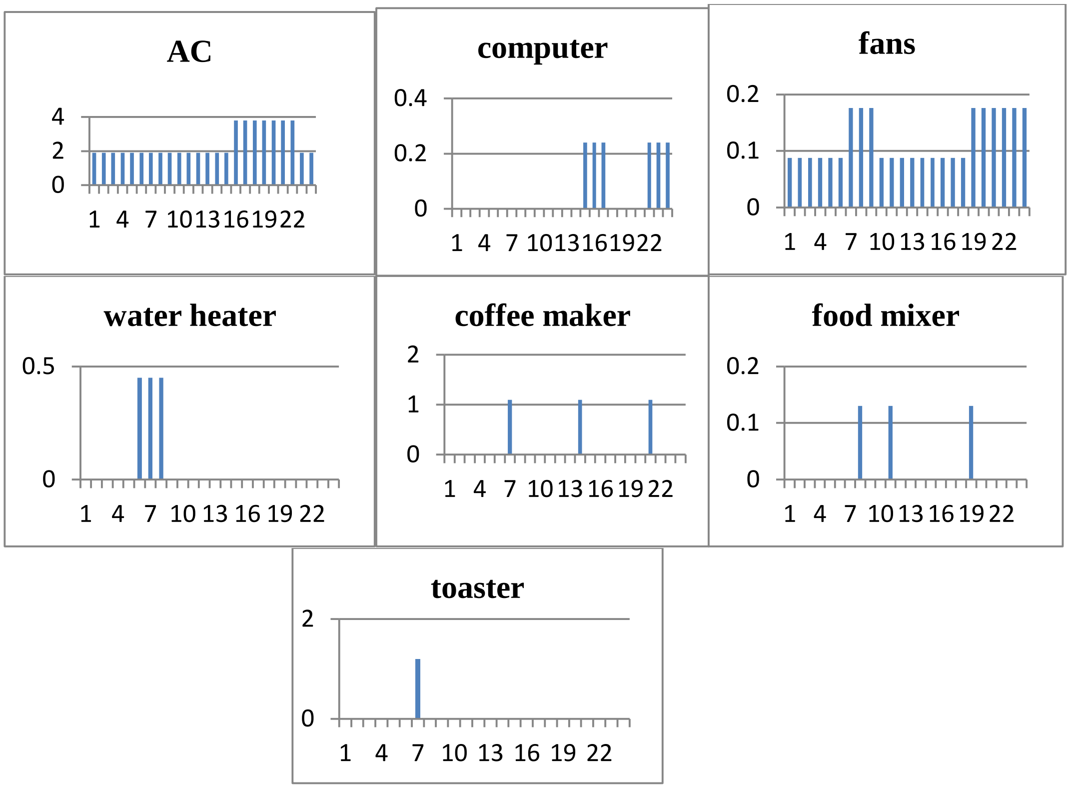


Figure 3.1. 24-hour consumption pattern of individual appliances for house 1

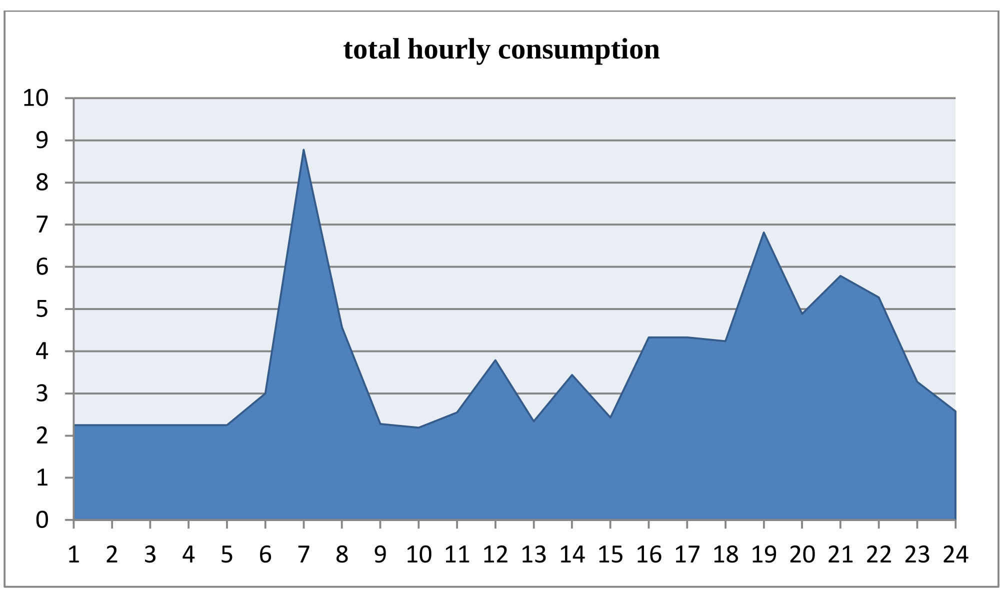


Figure 3.2. Demand curve for house 1on a weekday

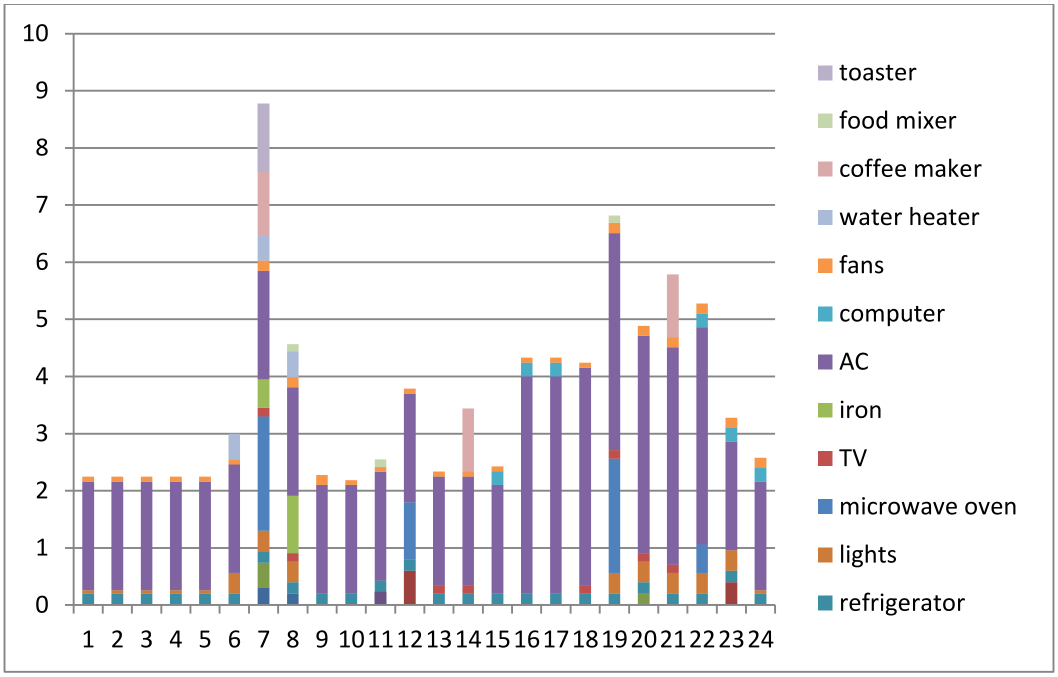


Figure 3.3. Hourly electricity consumption of house 1on a weekday

Table 3.4 tabulates the consumption of electricity for house 1 over a span of seven days i.e. for one entire week. The variation in energy consumption for different appliances is clearly visible on weekdays and weekends.

TABLE 3.4 : CONSUMPTION PATTERN FOR HOUSE 1 IN A GIVEN WEEK

Appliances/ Day	Washing-machine	Dish-washer	Boiler	Vacuum-cleaner	refrigerator	Light	Microwave-oven	TV	Iron	AC	Computer	Fans	Water-heater	Coffee- maker	Food-mixer	Toaster	Total
Mon	0.5	1	0.64	0.23	4.8	3.24	5.5	1.2	1.5	58.9	1.44	2.9	1.35	3.3	0.39	1.2	88.09
Tues	0.6	1.2	0.7	0.32	4.8	3.53	5.8	1.1	1.2	54.6	1.56	2.5	2.1	3.1	0.43	1	84.54
Wed	0.7	1.4	0.76	0.41	4.8	3.82	6.1	1	0.9	50.3	1.68	2.1	2.85	2.9	0.47	0.8	80.99
Thur	0.54	0.98	0.6	0	4.8	3.12	5.76	1.32	1.7	52.4	1.32	2.6	1.6	3.2	0.24	1.1	81.28
Fri	0.64	1.18	0.66	0.09	4.8	2.81	6.06	1.22	1.4	54.1	0.86	2.2	2.35	3	0.28	0.9	82.55
Sat	0.82	1.3	0.83	0	4.8	2.45	5.98	1.12	0.65	64.84	1.54	2.34	2.43	2.8	0.64	0.84	93.38
Sun	0.4	1.6	0.9	0.62	4.8	3.56	6.8	1.46	1.8	72.83	2.06	2.41	2.28	3.6	0.58	1.43	107.13
weekly average	0.6	1.24	0.727143	0.238571	4.8	3.218571	6	1.202857	1.307143	58.28143	1.49428571	2.435714	2.137143	3.128571	0.432857	1.038571	88.28

3.3. SIMULATIONS AND DISCUSSIONS

As any other GIS application, this web-based application also works with 3-tier architecture. The data for the two houses are saved in excel sheet, which in turn is saved on the server in the form of web-pages.

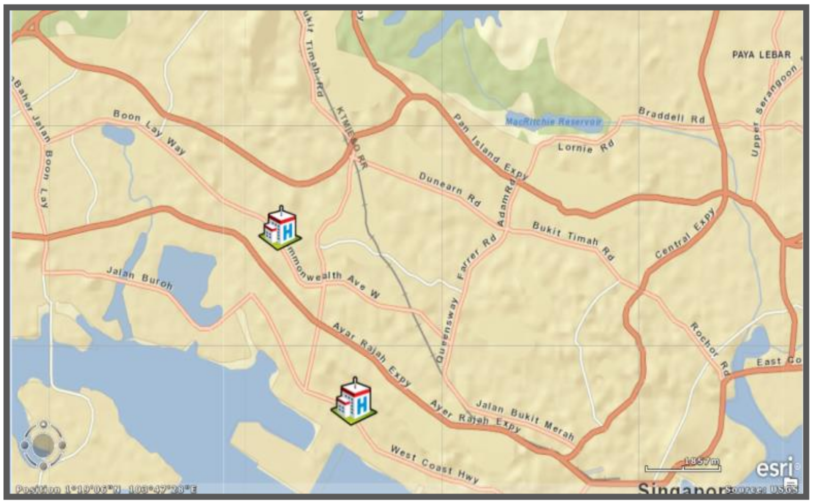
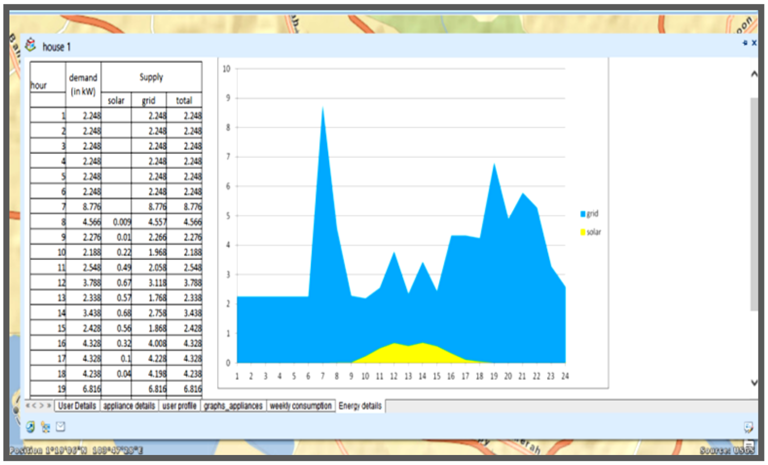


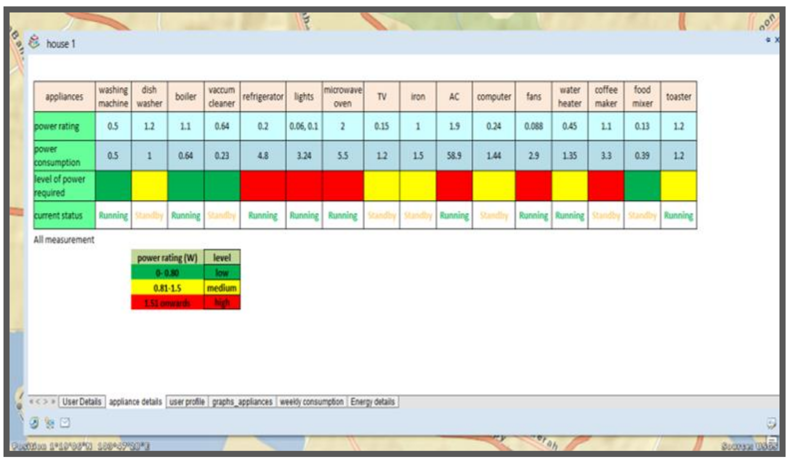
Figure 3.4. Sample houses on geographical map for ArcGIS system

In this case, the computer acts as database server. ArcMap is used for creation of information layer and ArcGIS Explorer Desktop is used to display the layers (information) on the map. The sample houses are pinned on the map as shown in figure 3.4. The server also stores the geographical parameters (latitudes and longitudes) for both the houses. Any data from the grid, pertaining to either of the map-points is stored on the server, corresponding to that particular map-point. When the user clicks on any icon on the map, all the information related to that particular house gets displayed on the screen as shown in figure 3.5. On clicking on the house 1 icon, the entire data from the server gets downloaded on the map, in the same format as saved on the server. The user can retrieve the desirable data and act accordingly, which is crucial for optimization of the demand curve. Figures 3.5. (a)-

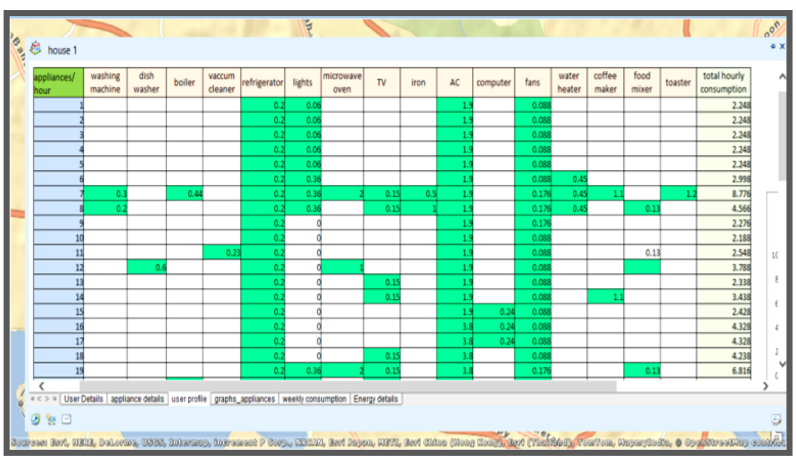
(c) show the data displayed for house 1. This data gets displayed on the real-time scenario.



(a) Energy details of house 1



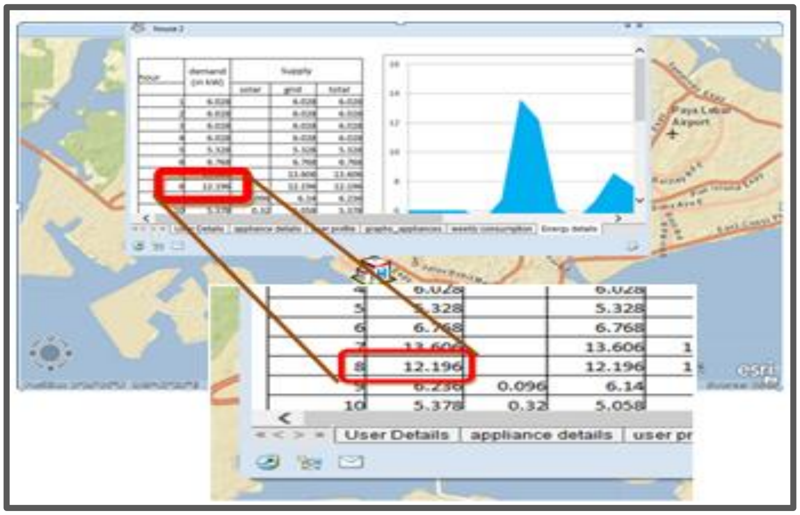
(b) Appliance details of house 1



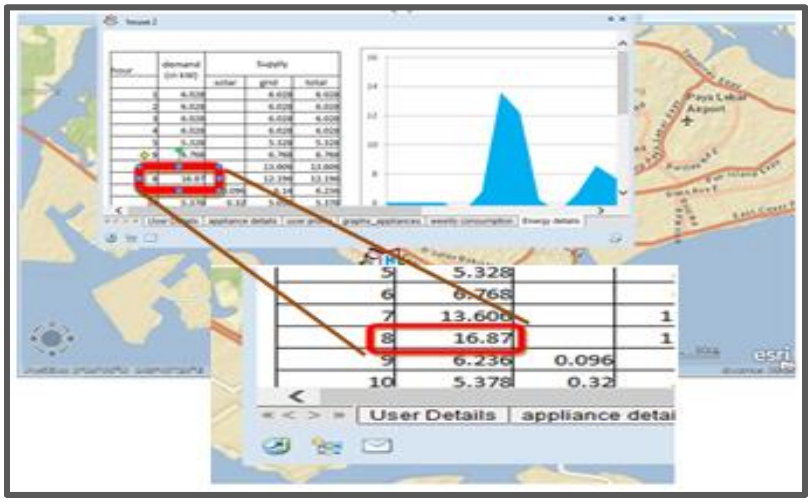
(c) User profile of house 1

Figure 3.5. Displaying data of house 1 on the map using the real-time dashboard developed here

Any change made in the data in the grid gets reflected in the server immediately, which in turn gets reflected on the map. This ability of the system is explained here. Suppose the user clicks on house 2 icon. The data corresponding to house 2 gets displayed on the map. The value of a field is 12.196, which is energy demand in 8th hour of a day, as shown in figure 3.6.(a). The value of this field is deliberately changed to 16.87 on the server. This change automatically gets reflected on the map the moment map is refreshed, as shown in figure 3.6.(b).



(a) Previous data on the map



(b) New data gets reflected on the map

Figure 3.6. Ability of ArcGIS Explorer to display information in real-time environment

In this section of the work it has been shown how this dashboard is able to operate in real-time. As the data is available in real-time scenario in visual form, the utilities and the users can get a better understanding of the consumption pattern. In addition, the customers can visualize their own demand curve and reschedule their appliances depending on the electricity pricing, incentives available, availability from DERs, etc. Eventually, use of this system enables the users to optimize their demand and participate actively in demand side management.

This prototype is developed using ESRI's proprietary GIS package, ArcGIS. Though the system is efficient enough, as well as user-friendly, but it needs the developer to acquire license prior to usage, which is a costly affair. To overcome this limitation, the author has used a hybrid of open-source GIS and proprietary GIS, which is described in next chapter.

CHAPTER 4

DISPLAY DESIRED DATA ON MAP AND OPTIMIZATION OF DEMAND CURVE

4.1. 3-TIER ARCHITECTURE

Though a lot of work has been done using GIS in the field of smart grid, but most of them are limited to commercial GIS. In this piece of work a hybrid of commercial and open source GIS is used. There is a description about the role of GIS in optimization of the demand curve. As stated, here a hybrid of open source and proprietary GIS is used to create the system. QGIS (Quantum GIS), which is an open source package, is used for creation of layers/shapefiles in the application layer. These shapefiles along with other information is stored on the server. In the database tier, Apache (Bitnami) data server is used. ESRI's ArcGIS Explorer Desktop is used in the presentation layer, for displaying the information stored on apache server in the form of shapefiles. It has been clearly shown in figure 4.1.

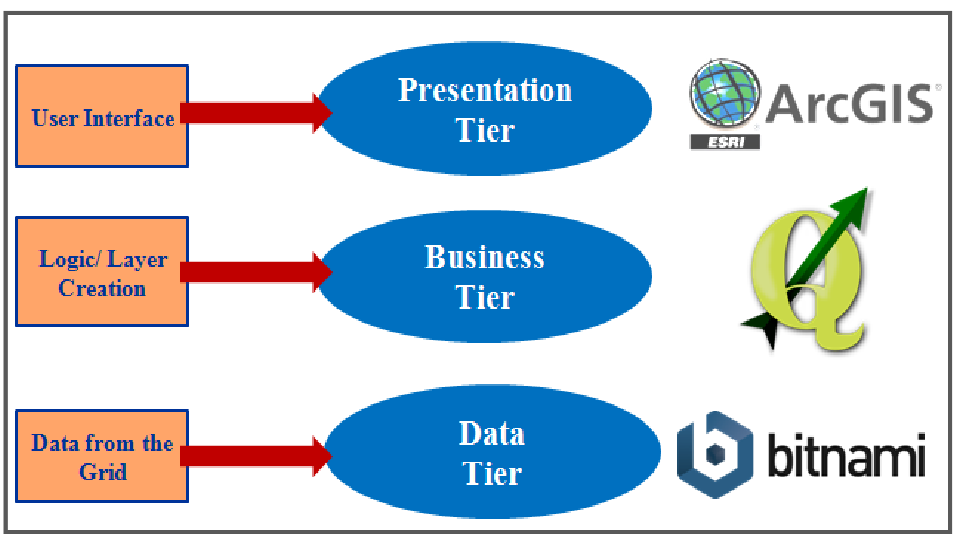


Figure 4.1. 3-tier architecture of the system

QGIS is an open source software and it is advantageous than any commercial software in quite a number of ways. It allows users to create multiple layers on the map and assemble them in different formats depending on the usage. In addition it extends facilities like data viewing, editing, and analysis capabilities. It can also store and help organizing the data in form of line, point or polygon, known as shapefiles. These shapefiles are not limited only to the parent software, but can also be used with other open source or proprietary software. For example a shapefile developed with QGIS can also be used with ArcGIS, GrassGIS, etc. It is written in C++, Python, Qt. and can run across various platforms including Windows, Linux, Android or iOS, hence providing users with the flexibility to work on various platforms suiting to their needs and comfort. It extends its own services/shapefiles to the community and can also use the external files/services available. This is the best option of OSS for the course of this work, owing to its advantages like fast in operations, free availability, and user-friendly. Though ArcGIS is commercial software, but ArcGIS Explorer Desktop is readily available making it fit for the purpose of this work. Other units of the package (like the ArGIS server and ArcMap) need to be purchased and their license must be updated, thus making them unsuitable for this work inspite of being an effective tool.

The Apache server is readily available and secure too. Its port, Bitnami, is used to store data/information. It is chosen to be used here as it can be deployed across various platforms like Windows, Mac and Linux [102]. A local host is created using Bitnami (bitnami-wampstack windows installer). As web applications are to be developed with Apache database, hence Wamp Server is needed which is a Windows web-development environment. WAMP stands for

Windows/Apache/MySQL/PHP, Python or PERL. It is a set of open source applications used in web server applications. It is a stack of four key elements of a web server namely operating system (Windows), database (Apache), database management system (MySQL), and web scripting language (Python, PHP, or PERL) [103].

4.2. DISPLAY DESIRED DATA ON MAP AND OPTIMIZATION OF DEMAND CURVE FOR INDIVIDUAL HOUSES IN A MICROGRID

4.2.1. OBJECTIVE

GIS users have the advantage of visualizing the data in natural fashion, without having in-depth knowledge of the underlying architecture or any query language. Improvement in service reliability, cost-reduction and energy efficiency are achievable, when the performance and management of electrical networks is optimized. The network can be optimized when the smart grid is made comprehensive in terms of visualization. The main objective of this section is to show how the demand curve for individual houses can be optimized when GIS is used for visualizing data/information from the grid on geographical map.

4.2.2. SYSTEM DESCRIPTION

4.2.2.1. SYSTEM MODEL

A typical modern residential microgrid has been simulated in MATLAB/Simulink, though the distributed energy sources are neglected for avoiding complexity in the system. The data obtained by simulating the grid is in excel files which are stored on the data server (Apache's Bitnami) in the form of web pages. This data is used for creation of shapefiles to display information on the map in the form of layers. QGIS is used for creation of shapefiles, which are displayed on the map using the real-time dashboard, created using ArcGIS explorer desktop. In general the data from the smart grid includes those related to energy consumption/demand; user profiling; generation and supply; energy supply from distributed energy resources, utility grid and diesel generator; details of appliances; running status of the appliances; details of the users; pattern of usage; etc. But for the scope of this work, the data is limited to details of users, demand from consumers, daily consumption, appliance details (including rating and time of usage), and optimized and unoptimized user profile. In this case the data is considered for scenario of Singapore, but it can be extended to smart grids throughout the world. The system model is shown in the figure 4.2.

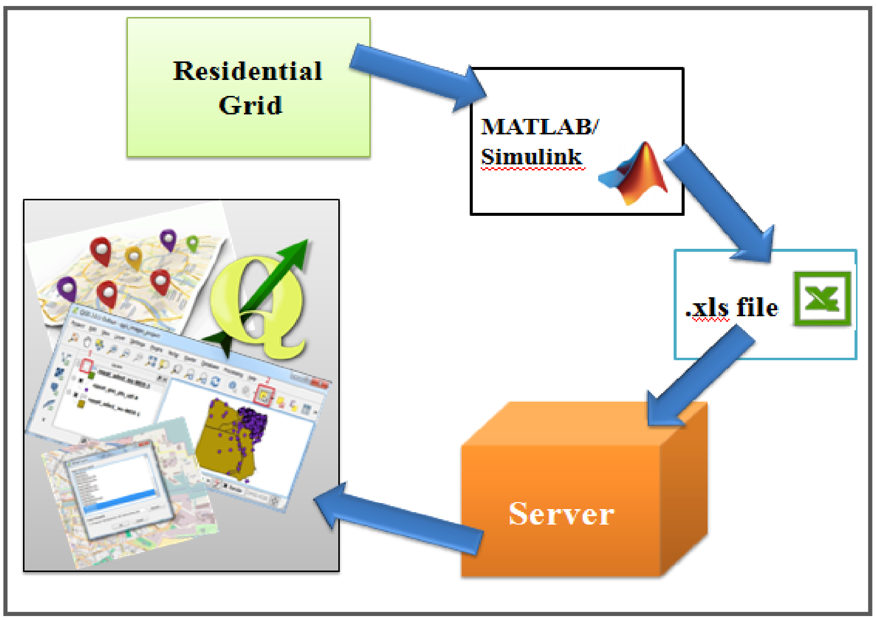


Figure 4.2. System model for the real-time dashboard using hybrid of ArcGIS and QGIS

The data on the server is organized in three groups and separate layers are created in QGIS for each group of data. Layer 1 holds information associated with users' details and appliances. Layer 2 comprises of current user profile data and demand curve for 24 hours. It also contains hourly consumption details of appliances. The third layer has all the data and graphs for optimized user profile. This user profile is obtained after the user amends the use of appliances by following the coordination game. Each layer is designed to have a hierarchical structure. Each of the layers has microgrid, neighborhoods, houses and loads in the hierarchical structure as shown in the figure 4.3.

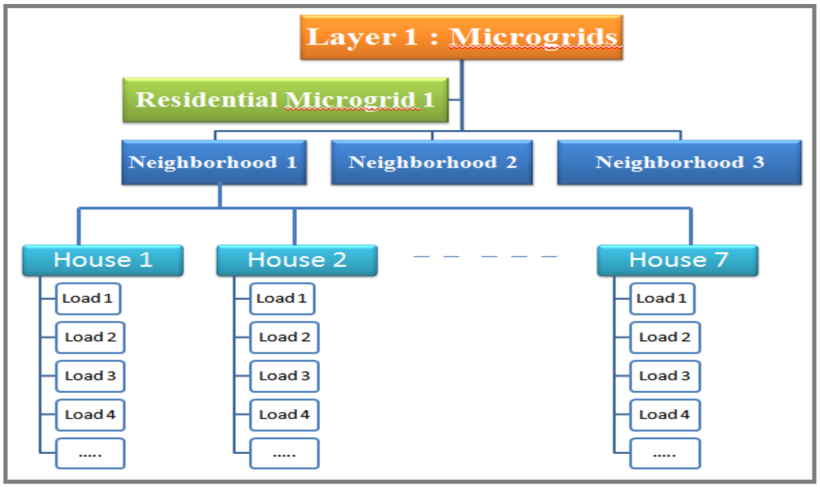


Figure 4.3. Hierarchy of layers in the residential microgrid

4.2.2.2. RESIDENTIAL MICROGRID

A residential microgrid is a small microgrid possessing all the software and hardware components present in a smart grid, including smart meters, energy storage devices, distributed energy resources (DERs like solar arrays, wind power generating stations, electric vehicles, etc.), home energy managers, grid monitoring infrastructure, etc., in addition to the communication and IT infrastructure. For the scope of work done in this section, a small residential microgrid (21 houses) is considered for the scenario of Singapore. It comprises of three neighborhoods with houses using the basic appliances (similar loads), as discussed in first section of this chapter. Though the loads are similar (as mentioned in table 3.1) but their number varies depending on the types of houses. For example, a 4-room HDB has 3 air conditioners while a 3-room HDB has only 2, unlike a 5-room HDB having 4. The number of houses is different in different neighborhoods. Neighborhood 1, 2 and 3 comprise of 7, 8 and 6 houses respectively. A detail of the types of houses considered for this system has been provided in table 4.1. The number of each appliances used in type of houses have been mentioned in table 4.2.

TABLE 4.1: TYPES OF HOUSES IN THE RESIDENTIAL MICROGRID

House/ Neighbourhood	**House 1**	**House 2**	**House 3**	**House 4**	**House 5**	**House 6**	**House 7**	**House 8**
Neighbourhood 1	2-Room	4-Room	5-Room	5-Room	2 Room	5-Room	3-Room	-
Neighbourhood 2	2-Room	4-Room	5-Room	5-Room	2 Room	5-Room	5-Room	3-Room
Neighbourhood 3	2-Room	4-Room	5-Room	5-Room	2 Room	3-Room	-	-

TABLE 4.2: NUMBER OF APPLIANCES IN DIFFERENT TYPES OF HOUSES

App/ Rooms	Washing Machine	Dish Washer	Boiler	Vacuum Cleaner	Refrigerator	Lights	Microwave Oven	TV	Iron	AC	Computer	Fans	Water Heater	Coffee Maker	Food Mixer	Toaster
2 room	1	1	1	1	1	4	1	1	1	1	2	2	1	1	1	1
3 room	1	1	1	1	1	5	1	1	1	2	3	3	1	1	1	1
4 room	1	1	1	1	1	7	1	1	1	3	4	4	2	1	1	1
5 room	1	1	1	1	1	8	1	1	1	4	6	5	2	1	1	1

The residential microgrid with the above mentioned data is simulated in MATLAB/Simulink. The layout of the residential grid which has been simulated in Simulink is shown in figure 4.4. Figures 4.5 and 4.6 show the connection of houses within a neighborhood and connection of loads within a house respectively. A typical residential grid has localized electricity generation stations like PV panels, wind turbines, EVs, etc., but to avoid the complications while doing simulations, they have been excluded from the system. These DERs shall be included in the future works.

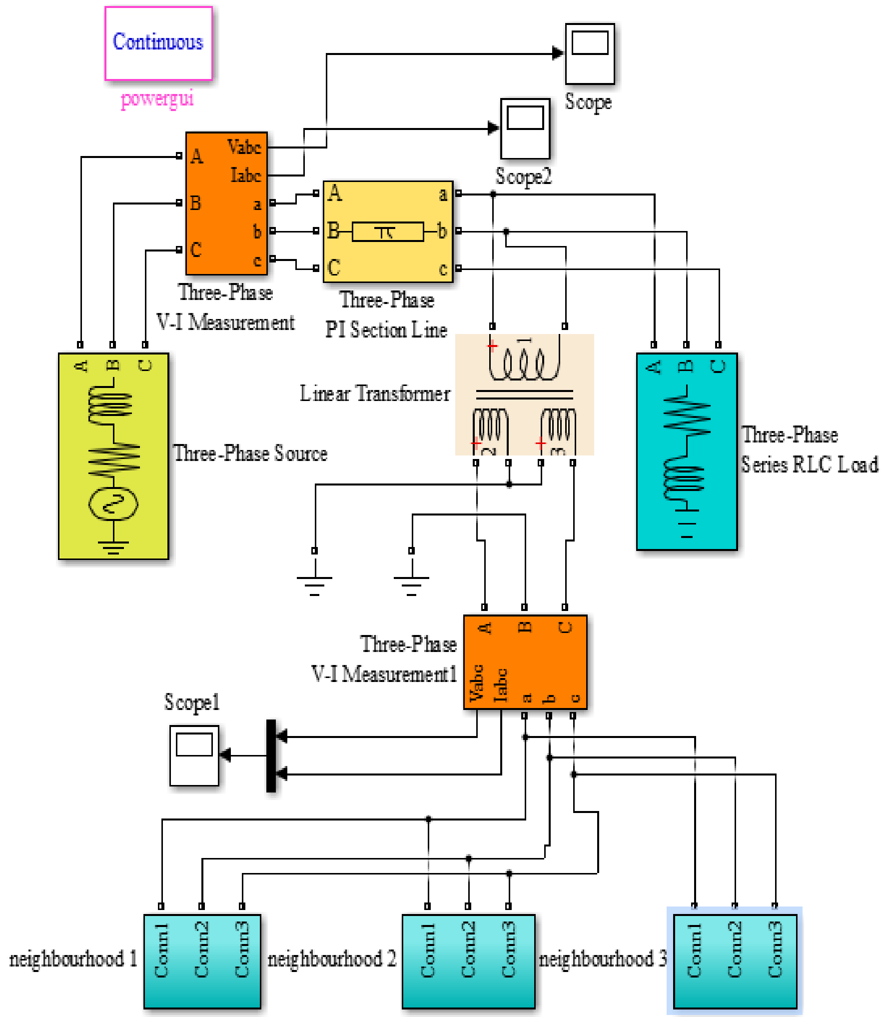


Figure 4.4. Layout of the Residential Grid used in the system, as developed in MATLAB/Simulink

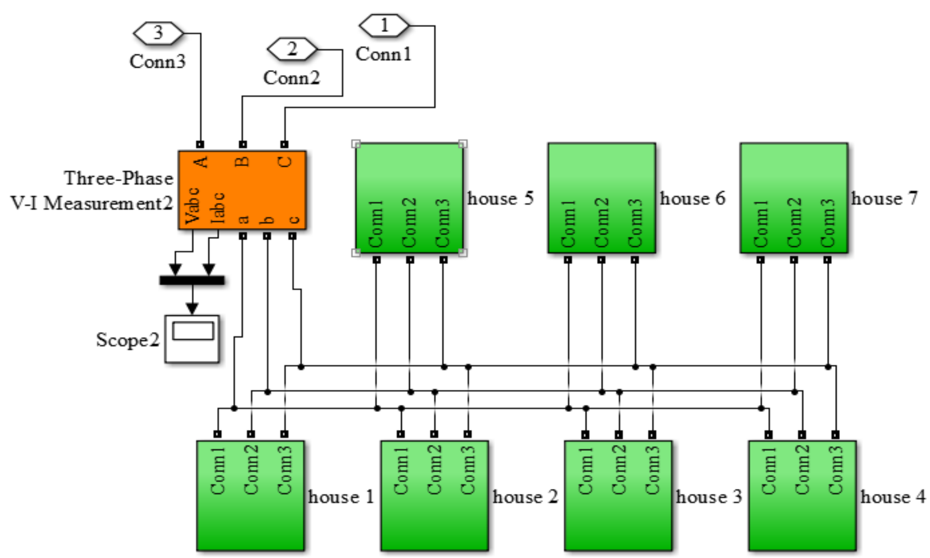


Figure 4.5. Connection of houses within a neighborhood

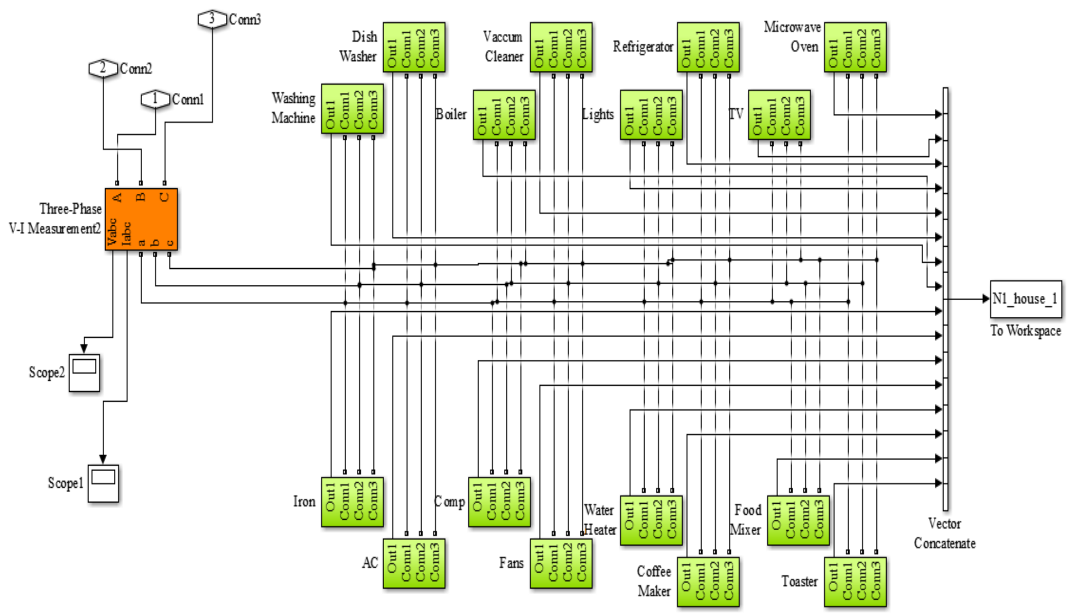
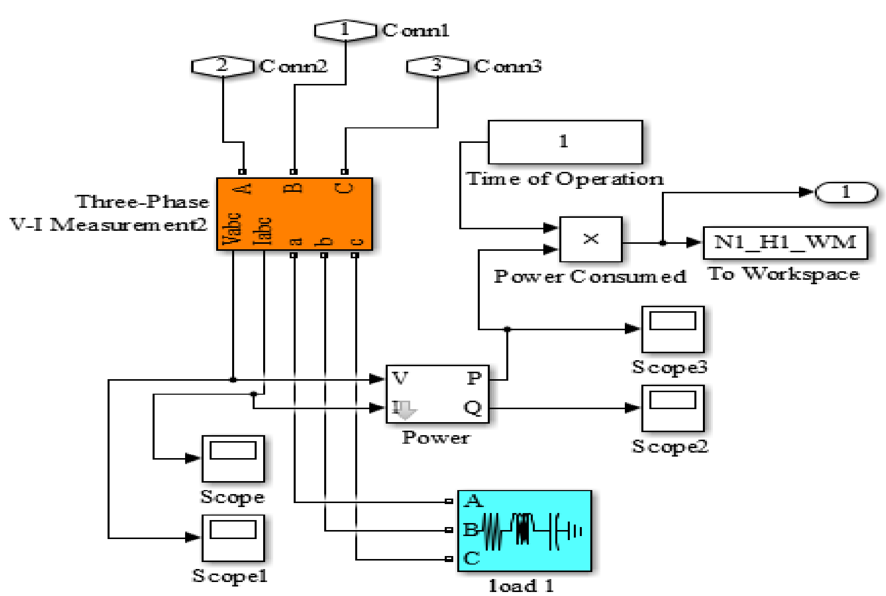
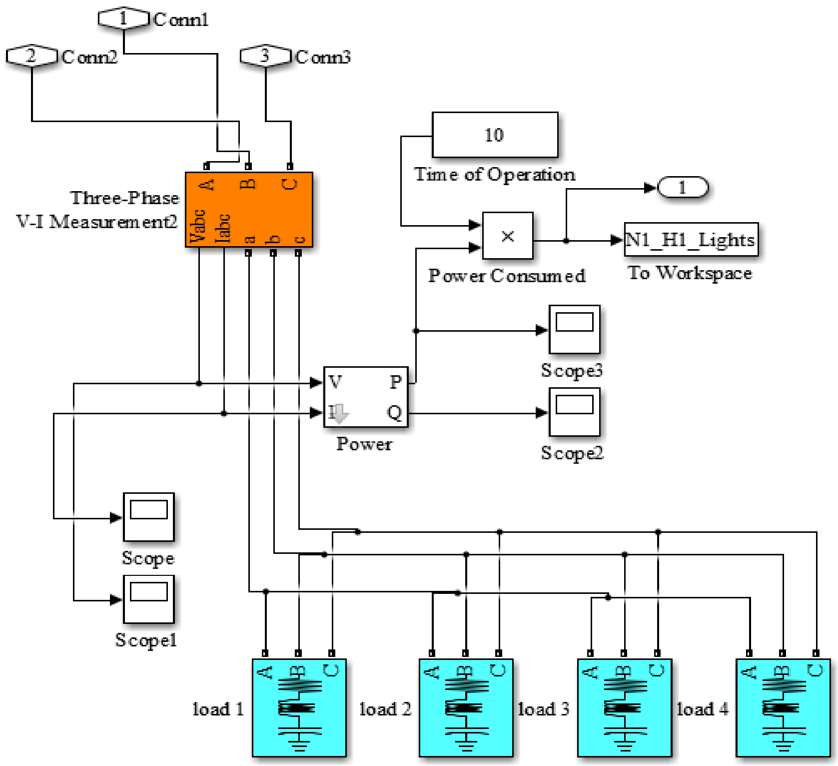


Figure 4.6. Connection of loads within a house

The data collected from the simulation screen to the workspace, which in turn is turn is stored in excel files. Each house has a separate excel sheet for recording the data on the server, where they are stored in the form of web pages. Figures 4.7 (a) and (b) show the connections for sending the signals back to the workspace, from washing machine and lights of house 1 of neighborhood 1.



(a)



(b)

Figure 4.7. Simulink network connection for (a). Exporting data for washing machine in house 1 of neighborhood 1 to workspace, and (b). Exporting data for lights in house 1 of neighborhood 1 to workspace

4.2.3. SIMULATIONS AND DISCUSSIONS

All the data recorded on the server is used to create shapefiles in QGIS, in the form of layers. There are three layers for houses in three different neighborhoods, and one layer for showing the neighborhood coverage areas. When the layers file is opened in QGIS, the layers get displayed on the map. Figure 4.8 is a screenshot from QGIS Desktop 2.10.1, when file corresponding to layer 1 is opened in QGIS. The second figure is zoomed view of the same QGIS screen in layer 1. Similar views are available for other two layers as well. These layers are saved on the server. When these layers are to be displayed to the user, they are downloaded on the ArcGIS Explorer Desktop through a feature called addition of shapefiles. Then the viewing mode is changed by going to the properties of every layer, so that the data gets displayed in the same format as stored on the server. Many others properties of the pop-up screen (the one which displays data) can be altered here.

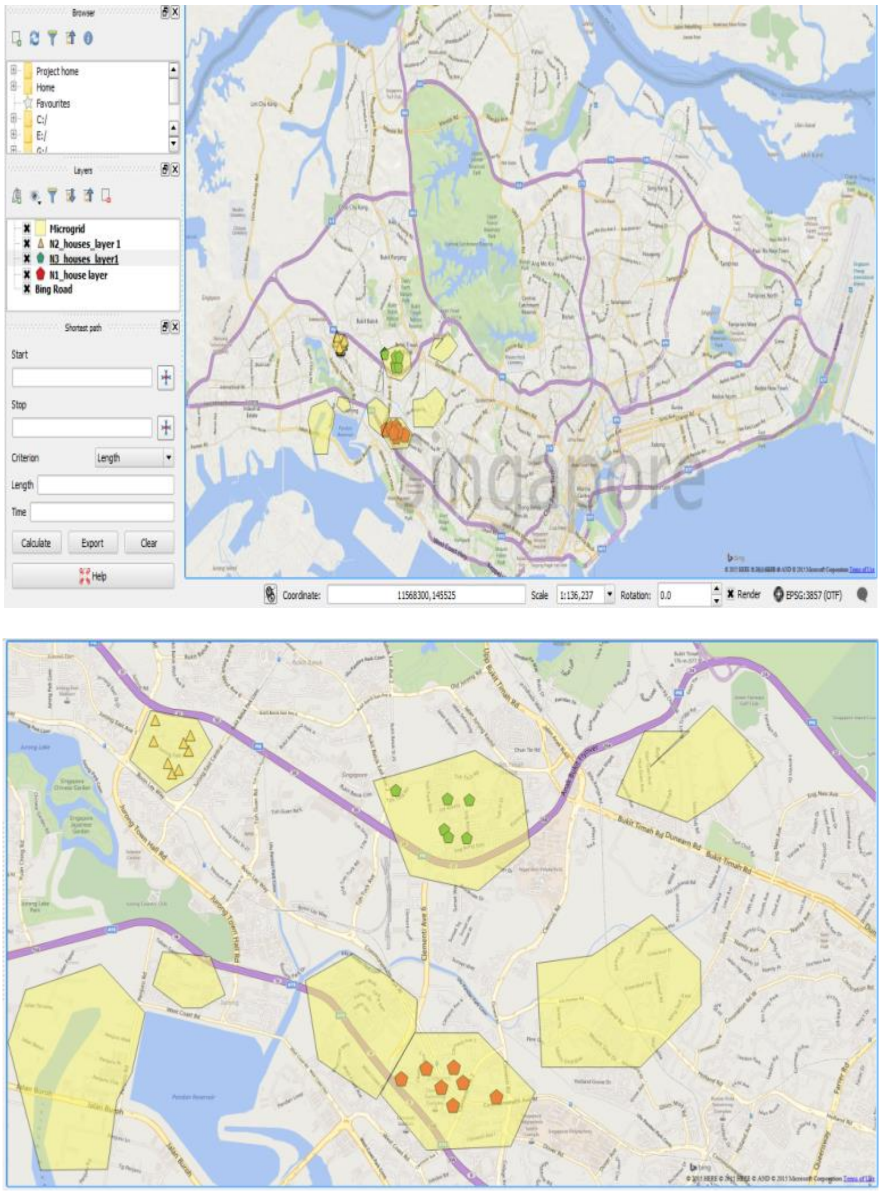


Figure 4.8. Visualization of layer 1 on QGIS

The data is present on the server in the form of layers, after creation of shapefiles in QGIS. This makes the accessing of data easier and faster in the presentation layer (ArcGIS Explorer), when a query is placed. Only selected portion of the data/information is downloaded on the map, as per the user's requirement. For example it is possible to select only a particular neighborhood and view data of houses in that neighborhood. This helps to escape needless downloading of the complete database when only a portion of it is required. Figure 4.9 shows screenshot of ArcGIS Explorer Desktop when layer 1 and all its neighborhoods are selected. Figure 4.10 shows the screenshot when only neighborhood 3 of layer 1 is selected. In both of the cases, the microgrid layer is also selected, which shows all the neighborhood areas (represented in yellow color polygons). All the other layers are deselected to avoid downloading of unnecessary data from the server. The users can do this for all other layers, depending on what kind of data is needed.

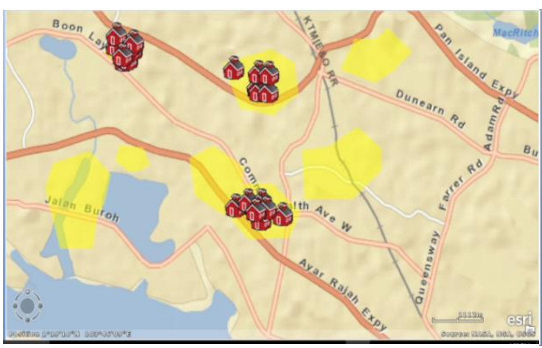
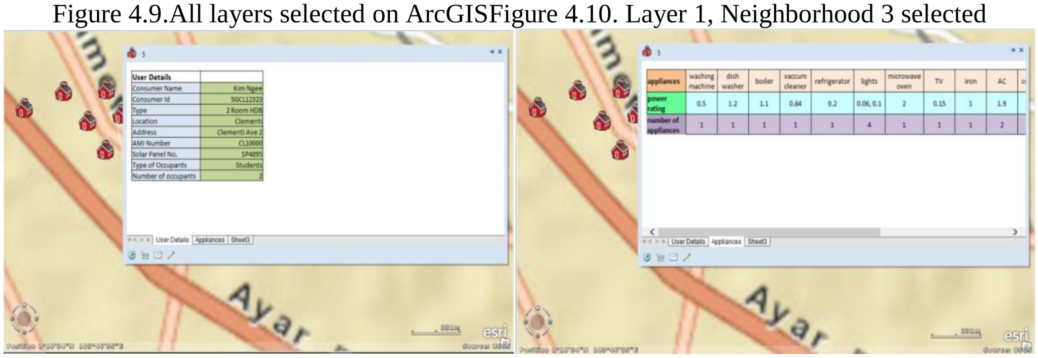


Figure 4.9.All layers selected on ArcGISFigure 4.10. Layer 1, Neighborhood 3 selected



(a) (b)

Figure 4.11. House 5 of neighborhood 1 in layer 1 selected on ArcGIS Explorer Desktop

When a particular microgrid of a layer is selected, all the houses of that layer are visible to the user. The user can have access to details of all the houses of that microgrid. In the above example, neighborhood 1 of layer 1 is selected. As layer 1 contains the details of the customers and the appliances present in every house, the users can retrieve the same upon clicking on a house, as shown in figure 4.11. The user here clicks on house 5 of neighbourhood 1 in layer 1.

When house 1 of neighborhood 1 in layer 2 is clicked on, the window shown in figure 4.12 appears on the screen, which contains information of the user's daily consumption and the current user profile. Similarly, when the user selects neighbourhood 1 of layer 3 and clicks on house 1, then the windows containing the optimized user profile appears on the screen as shown in figure 4.13.

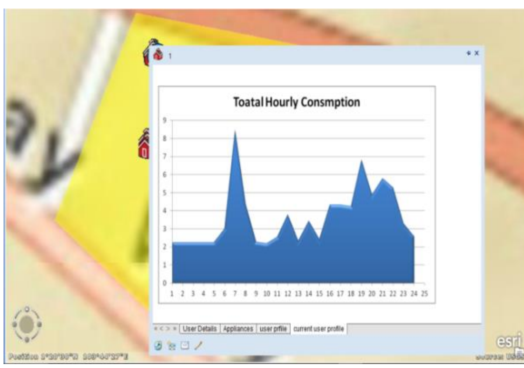


Figure 4.12. House 1 of neighborhood 1 in layer 2 selected on ArcGIS Explorer Desktop

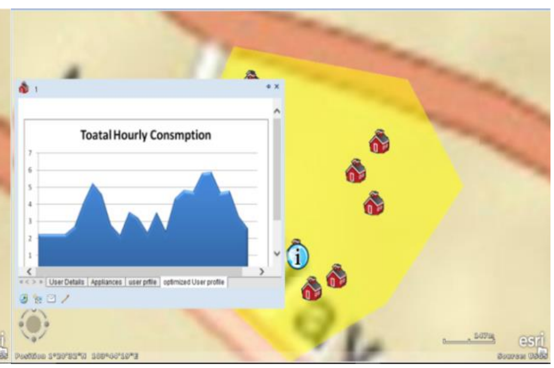


Figure 4.13. House 1 of neighborhood 1 in layer 3selected on ArcGIS Explorer Desktop

The difference between demand curves is conspicuous in figures 4.12 and 4.13. The graph in figure 4.12 shows the unoptimized user profile but the one in 4.13 shows the optimized user profile, when the user takes suitable action for appliance scheduling after looking at the consumption pattern.

Tables 4.3 and 4.4 show the consumption pattern of house 1 of neighborhood 2, before and after the rescheduling of appliances. From the tables it becomes visible that the user is highly motivated for rescheduling the appliances in order to optimize the demand curve.

TABLE 4.3. CONSUMPTION PATTERN OF HOUSE 1 IN NEIGHBORBORHOOD 2 BEFORE RESCHEDULING OF APPLIANCES

Appliances/hour	Dish-washer	Boiler	Vacuum-cleaner	refrigerator	Light	Microwave-oven	TV	Iron	AC	Computer	Fans	Water-heater	Coffee- maker	Food-mixer	Toaster	Total hourly consumption
1				0.2	0.06				1.9		0.088					2.248
2				0.2	0.06				1.9		0.088					2.248
3				0.2	0.06				1.9		0.088					2.248
4				0.2	0.06				1.9		0.088					2.248
5				0.2	0.06				1.9		0.088					2.248
6				0.2	0.36				1.9		0.088	0.45				2.998
7		0.44		0.2	0.36	2	0.15	0.5	1.9		0.176	0.45	1.1		1.2	8.476
8				0.2	0.36		0.15	1	1.9		0.176	0.45		0.13		4.366
9				0.2	0				1.9		0.176					2.276
10				0.2	0				1.9		0.088					2.188
11			0.23	0.2	0				1.9		0.088			0.13		2.548
12	0.6			0.2	0	1			1.9		0.088					3.788
13				0.2	0		0.15		1.9		0.088					2.338
14				0.2	0		0.15		1.9		0.088		1.1			3.438
15				0.2	0				1.9	0.24	0.088					2.428
16				0.2	0				3.8	0.24	0.088					4.328
17				0.2	0				3.8	0.24	0.088					4.328
18				0.2	0		0.15		3.8		0.088					4.238
19				0.2	0.36	2	0.15		3.8		0.176			0.13		6.816
20		0.2		0.2	0.36		0.15		3.8		0.176					4.886
21				0.2	0.36		0.15		3.8		0.176		1.1			5.786
22				0.2	0.36	0.5			3.8	0.24	0.176					5.276
23	0.4			0.2	0.36				1.9	0.24	0.176					3.276
24				0.2	0.06				1.9	0.24	0.176					2.576

TABLE 4.4. CONSUMPTION PATTERN OF HOUSE 1 IN NEIGHBORBORHOOD 2 AFTER RESCHEDULING OF APPLIANCES

Appliances/hour	Dish-washer	Boiler	Vacuum-cleaner	refrigerator	Light	Microwave-oven	TV	Iron	AC	Computer	Fans	Water-heater	Coffee- maker	Food-mixer	Toaster	Total hourly consumption
1				0.2	0.06				1.9		0.088					2.248
2				0.2	0.06				1.9		0.088					2.248
3				0.2	0.06				1.9		0.088					2.248
4				0.2	0.06				1.9		0.088					2.248
5		0.44		0.2	0.06				1.9		0.088					2.688

6				0.2	0.36				1.9		0.088	0.45	0.5		0.6	4.098
7				0.2	0.36	2	0.15		1.9		0.176	0.45				5.236
8				0.2	0.36		0.15		1.9		0.176	0.45	0.6	0.13	0.6	4.566
9				0.2	0			0.5	1.9		0.176					2.776
10				0.2	0				1.9		0.088					2.188
11			0.23	0.2	0			1	1.9		0.088			0.13		3.548
12				0.2	0	1			1.9		0.088					3.188
13				0.2	0		0.15		1.9		0.088					2.338
14	0.6			0.2	0		0.15		1.9		0.088		0.6			3.538
15				0.2	0				1.9	0.24	0.088					2.428
15				0.2	0				3.8	0.24	0.088					4.328
17				0.2	0				3.8	0.24	0.088		0.5			4.828
18				0.2	0		0.15		3.8		0.088		0.5			4.738
19				0.2	0.36	1	0.15		3.8		0.176			0.13		5.816
20		0.2		0.2	0.36	1	0.15		3.8		0.176					5.886
21				0.2	0.36		0.15		3.8		0.176					4.686
22				0.2	0.36				3.8	0.24	0.176					4.776
23	0.4			0.2	0.36				1.9	0.24	0.176					3.276
24				0.2	0.06				1.9	0.24	0.176					2.576

Figure 4.14 shows how the demand curve gets optimized when rescheduling of appliances is done.

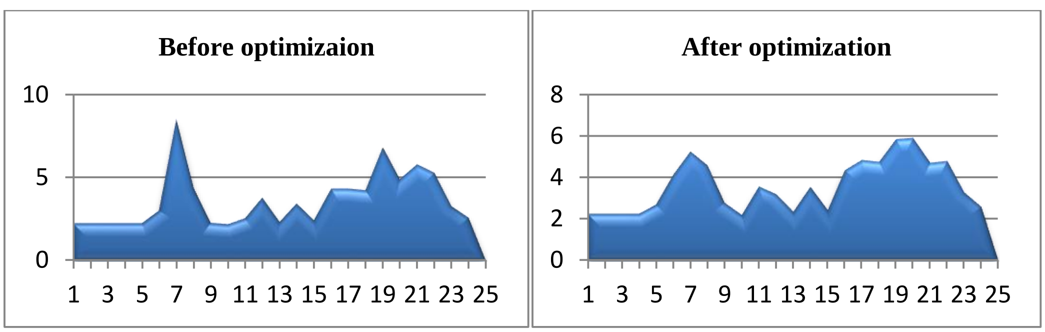


Figure 4.14. Demand curves for house 1 of neighborhood 2 before and after optimization

Hence it can be said that this system motivates the customers to adopt demand side management in day to day lives, as their own consumption behavior is made visible to them on the map. They don't have to stream through the pool of data for getting any data/information; rather this is all available to them in the form of graph, charts, tables, etc. on the map in a segregated form. In addition to their own consumption pattern, different schemes can also be made available to the users, which further motivate them to participate in active functioning of the system contributing to demand side management. There are many optimization algorithms designed by researchers across this research area which help to optimize the demand response, contributing to demand side management. These algorithms can be for cost optimization or appliance scheduling, depending on the need of the users/utility-operators/aggregators. One such algorithm has been created for the optimization of demand curve. This can be developed using Python code and implemented in QGIS. This algorithm is meant to optimize the user profile by rescheduling the appliances. The users schedule their appliances for the entire day. Upon visualizing their own demand response through this dashboard (as shown in first graph of figure 4.14), the users reschedule their appliances using the algorithm below. Thereafter they can view their own demand response (as shown in second graph of figure 4.14). This can be done by the user multiple number of times depending on the energy availability and cost of electricity, hence contributing to the demand side management.

Algorithm: Schedule_Optimization

Peep(T_i, Ap_i)
{ *Input:*
T_i = *Time Slot*
Ap_i = *Appliance Load*
Begin: At T_i
Check: {$P_{available} > P_{appliance}$
And
$P_{unused} + P_{appliance} < P_{threshold}$}
Then: *Run* (Ap_i)
Return 1;
Else: *Wait* (T_i)
Return 0;}
Priority (Ap_i)

```
{   Input:
   n= number of currently running appliances
          Begin:
                If Peep(T_i, Ap_i) = = 0
                {  For (k=1 to k=n)
                Check:If (Priority (Ap_k) < Priority (Ap_i))
         Stop (Ap_i)
                Else
                    Run (Ap_i)
                    Break;
}}}
```

4.3. DISPLAY DESIRED DATA ON MAP FROM INDIVIDUAL HOUSES, NEIGHBORHOODS, MICROGRIDS AND OVERALL GRID AND OPTIMIZATION OF DEMAND CURVE

4.3.1. OBJECTIVE

This section is an extension of the previous section having more number of houses with larger variation in the sample space of houses considered. Here the data displayed in the map is not only for individual houses but also for cluster of houses. This cluster may be a neighborhood in a given microgrid, or a microgrid itself. For this system, there are different layers for displaying data in different hierarchy. The hierarchy for displaying the data includes:

1. Data from individual houses
2. Data for every neighborhood in a residential microgrid
3. Data for every residential microgrid in the grid
4. Data of all the microgrids together

This visualization helps to optimize the demand curve at every level, starting from the house level to grid level. The number of microgrids considered here are larger.

4.3.2. SYSTEMDESCRIPTION

As in the previous system, even here the 3-tier architecture is used and the same combination of software is used for creating the logic and the dashboard. Even the system model remains the same as shown in figure 4.15. For every level of hierarchy one layer is created. Figure 4.16 shows the hierarchy in the system.

Figure 4.15. System Model

The system comprises of five residential microgrids namely M1, M2,… M5. Each of the microgrids has certain neighborhoods with specified number of houses. M1 has four neighborhoods, N1, N2, N3, N4 with 500, 400, 600, 500 houses respectively. M2 has five neighborhoods, N1, N2, N3, N4, N5 with 300, 400, 500, 300, 600 houses respectively. M3 has five neighborhoods, N1, N2, N3, N4, N5 with 400, 500, 300, 600, 400 houses respectively. M4 has three neighborhoods, N1, N2, N3 with 400, 500, 600 houses respectively. M5 has four neighborhoods, N1, N2, N3, N4 with 600, 600, 600, 600 houses respectively. So the system comprises of 10200 houses. The houses created here are more diverse as compared to the previous system with more variance in the appliances used. Table 4.5 shows the diversity of types and number of appliances in different types of houses in the system.

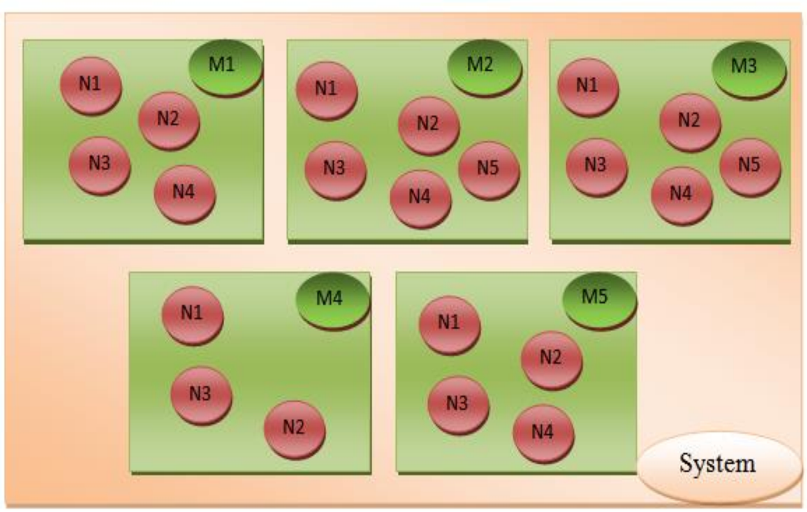


Figure 4.16. Hierarchy in the grid

TABLE 4.5. NUMBER OF APPLIANCES IN DIFFERENT TYPES OF HOUSES

Appliances/ House	**Rating (in W)**	**2-Room**		**3- Room**		**4-Room**		**5-Room**	
Occupants		Students	Family	Students	Family	Students	Family	Students	Family
Washing Machine	500	1	1	1	1	1	1	1	1
Dish Washer	1200	1	1	1	1	1	1	1	1
Boiler	1100	1	1	1	1	1	1	1	1
Vacuum Cleaner	640	1	1	1	1	1	1	1	1
Refrigerator	200	1	1	1	1	1	1	1	1
Lights	60	2	3	3	1	3	2	3	8
	100	2	1	3	1	4	5	5	0
Microwave Oven	2000	1	1	1	1	1	1	1	1
TV	150	1	1	1	1	1	2	1	2
Iron	1000	1	1	2	1	2	1	3	1
AC	1900	2	1	2	1	3	2	5	3
Computer	240	2	1	3	1	4	2	6	2
Ceiling Fan	88	2	1	3	2	4	2	5	5
Table Fan		1	1	1	1	2	1	3	1
Water Heater	450	1	1	1	1	2	2	2	2
Coffee Maker	1100	1	1	1	1	1	1	1	1
Food Mixer	130	1	1	1	1	1	1	1	1
Toaster	1200	1	1	1	1	1	1	1	1

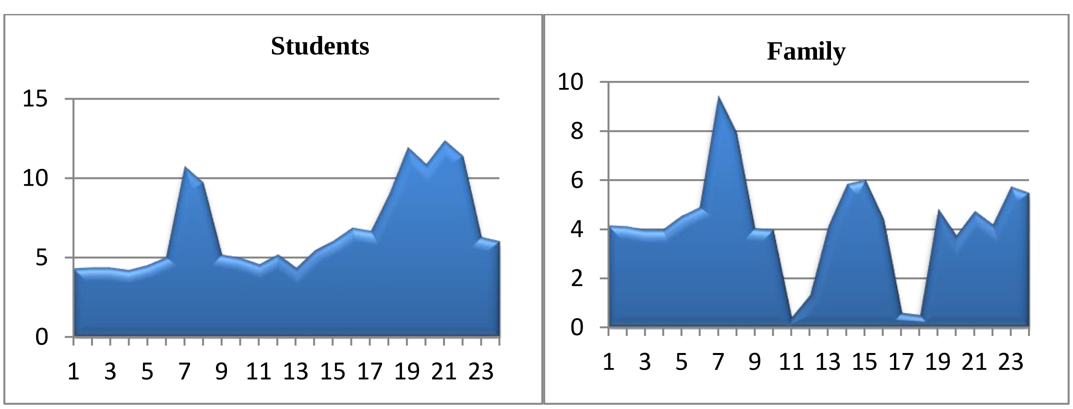


Figure 4.17. Demand curves to show energy consumption of 5-room HDB when occupied by students and family

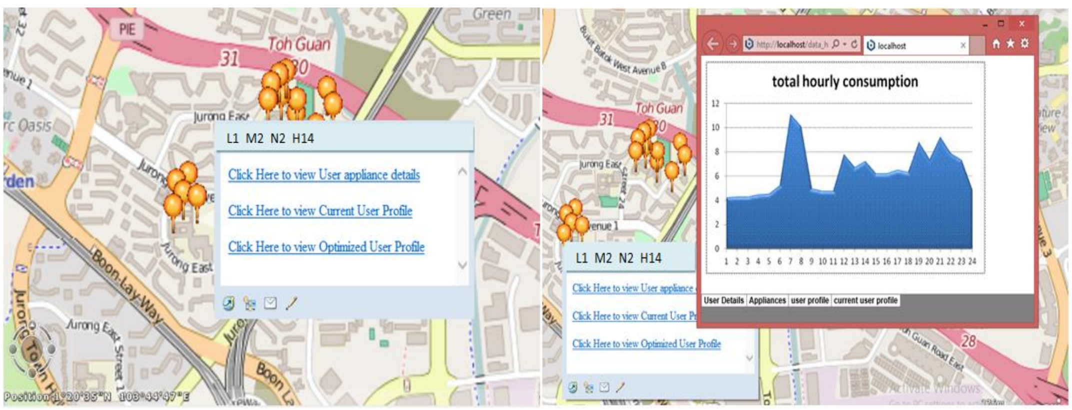
The usage pattern depends not only on the number of appliances and number of rooms but also on the type of occupants. For example, the same 5-room house has different demand curves when occupied by a family and when occupied by students, as shown in figure 4.17.

Depending on these variations of houses, a residential microgrid is designed in MATLAB/Simulink. Using the data obtained from simulation of the grid, shapefiles are created in QGIS in the form of layers. Layer 1 displays information from the individual houses. Layer 2 displays information from every neighborhood. Layer 3 displays information of every residential microgrid. These layers are then used in ArcGIS Explorer Desktop to display the information to the users. This has been illustrated further in the next sub-section.

4.3.3. SIMULATIONSAND DISCUSSIONS

Using QGIS the shapefiles are created and stored on the server in the form of layers as it has been done in the previous section. As discussed earlier, layer 1 is used for displaying data for individual houses, layer 2 for individual neighborhoods, and layer 3 for individual microgrids. These shapefiles are then opened with ArcGIS Explorer Desktop, which forms the presentation tier of the system. The user can select the layers depending on which level of information he wants to see and that particular information gets downloaded on the map.

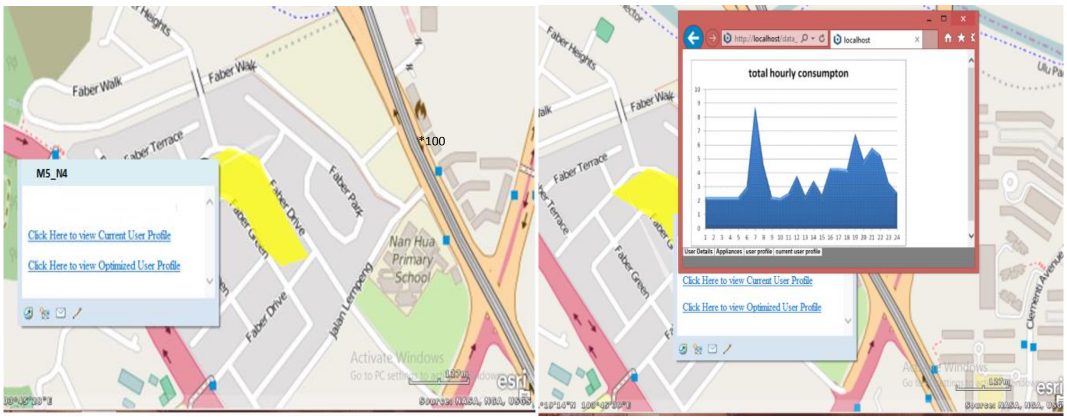
If the user intends to view data for individual houses, layer 1 is selected and the particular house of desired neighborhood in a given residential microgrid is clicked upon. Upon clicking the house, links for data related to the selected house appear on the screen. The user can click on the relevant link to get the desired data. For example, the user wishes to view information of house H-14 of neighborhood N-2 in microgrid M-2, named L1_M2_N2_H14. Figure 4.22 shows the screenshots of the ArcGIS Explorer Desktop illustrating this case. When the user clicks on house L1_M2_N2_H14, a window pops up as shown in figure 4.18 (a). The user is provided with three options to view different types of data associated with the selected house. These options are in the form of web-links, which link to data stored on the server. Say the user intends to view current user profile. So the second link can be clicked upon as a result of which the current user profile of house L1_M2_N2_H14 is displayed on the map as shown in figure 4.18 (b).



(a) (b)

Figure 4.18.Display of data for individual house L1_M2_N2_H14

If the user wishes to see data of a particular neighborhood of a given residential microgrid, then he can simply select layer 2 and then the desired neighborhood in that. Similar screen appears on the dashboard as in the previous case, only the difference being that here it is for one entire neighborhood (comprising of all the 600 houses in that cluster) and not of a single house as in the previous case. For example, if the user wishes to see the demand curve of the neighborhood 4 of microgrid 5, then he can simply select the neighborhood M5_N4 and view the demand curve of the selected neighborhood as illustrated in figure 4.19.



(a) (b)

Figure 4.19.Display of data for individual neighborhood M5_N4

Similarly, when the user goes to layer 3, it is possible to view the energy consumption/demand curve of individual microgrids. When the user selects a microgrid the overall details of that microgrid are shown. For example, if the user selects microgrid M3, then the consumption of all the houses of all the neighborhoods of that microgrid i.e. consumption of all 2200 houses (M1_N1_H1 to M1_N1_H400, M1_N2_H1 to M1_N2_H500, M1_N3_H1 to M1_N3_H300, M1_N4_H1 to M1_N4_H600, M1_N5_H1 to M1_N5_H400) will be displayed on the dashboard, in the form of a graph which is the demand curve.

Here a basic structure has been designed, where one unit/house, one neighborhood or one microgrid is considered at a time. With the use of python coding, it might be possible to create a system where user can select multiple units from a system but not the whole system, which comes under the future scope of this section. For example, if the user wishes to see the consumption pattern of ten houses in a given neighborhood of a microgrid, then by making a selection of those particular houses the demand curve of those houses can be seen. Similarly if the user wishes to see the demand curve of certain neighborhoods and not of all of those in a microgrid, then also it can be made possible. All that is required is the requirements from the users of the system, according to which the system can be customized.

The advantage of using this system is that the users will get idea of their own energy consumption and energy availability in their microgrid as well as the neighboring microgrids. Depending on the perks announced by the utility operators and comparing their own energy status with others, the residents of a given microgrid might get encouraged to make more judicious use of the available energy. In addition, sharing of energy among microgrids is promoted because now the status of energy is visible to the users through this system.

The role of aggregators becomes quite pronounced here. Though the concept of demand response is meant for adding smartness to the grid and is applicable in every sector of the grid, but its acceptance by the customers is yet not prompt. It is difficult to convince customers and make them aware of the real benefits available to them. Even if the user is convinced about the benefits there is lack of interest from user's side because the utility operators tend to derive most benefits for themselves rather than extending it to the consumers, as the consumers form a very small portion of the entire demand response curve leading to constrained negotiation power. Also, owing to the large number of the households, the utility operators are unable to design and apply adequate demand response techniques. Hence, the aggregator is needed, which is a broker between the consumer and the utility provider. Each aggregator has the technology and responsibility to perform demand response for a fixed number of units. As an aggregator holds significant number of units under it, it has the capability to negotiate with the utility operator in an efficient manner [132]. Additionally, it has a greater influence on the users as the users get benefitted in a better way with the actions and negotiations of aggregators with the utility operators. The users get enrolled in demand response program offered by aggregators to form a bigger unit as many small units enroll for the same program, eventually increasing the negotiation power. The hierarchy in the power system in the presence of aggregators is shown in figure 4.20.

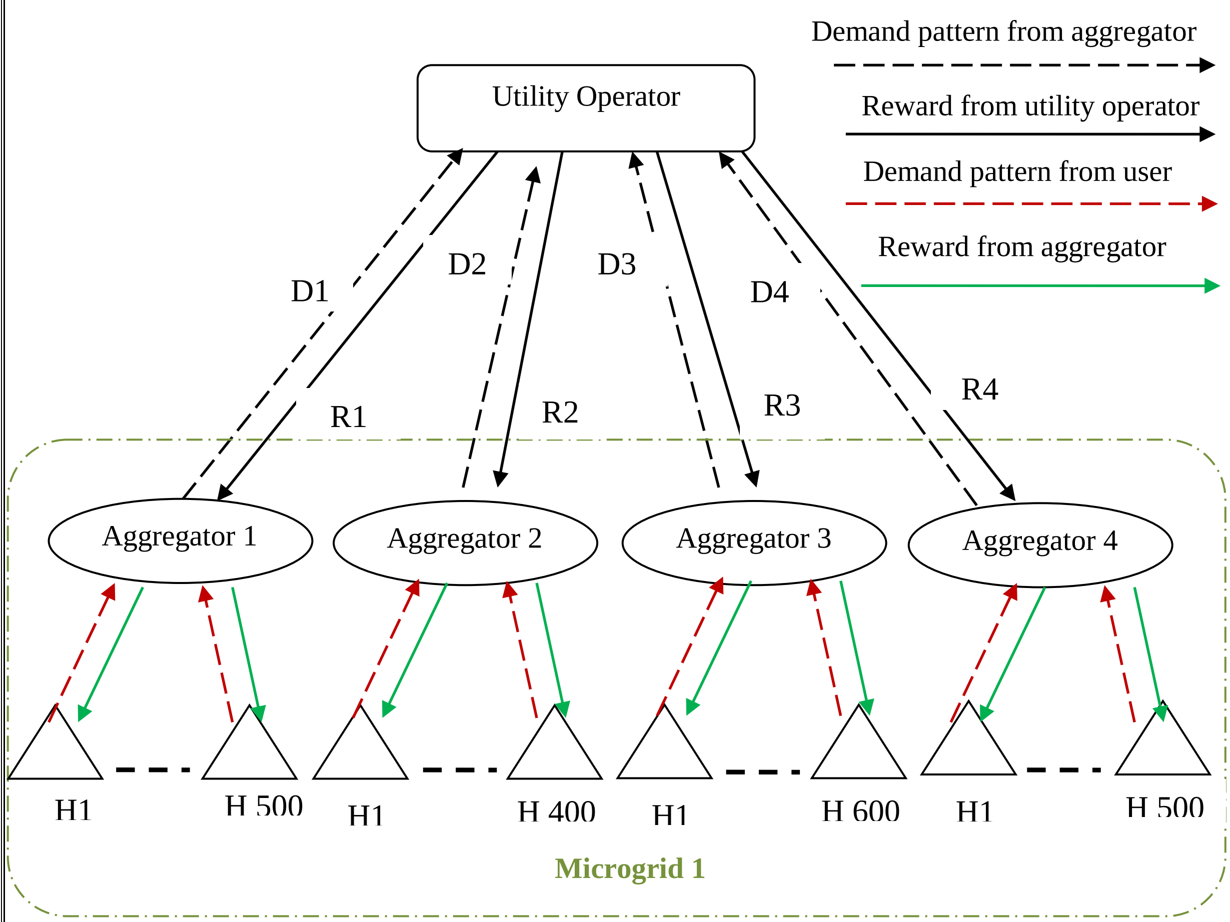


Figure 4.20. Hierarchy of power system with aggregators

The process for working of an aggregator while implementing visualization of power system information using GIS is shown as a flowchart in figure 4.21.

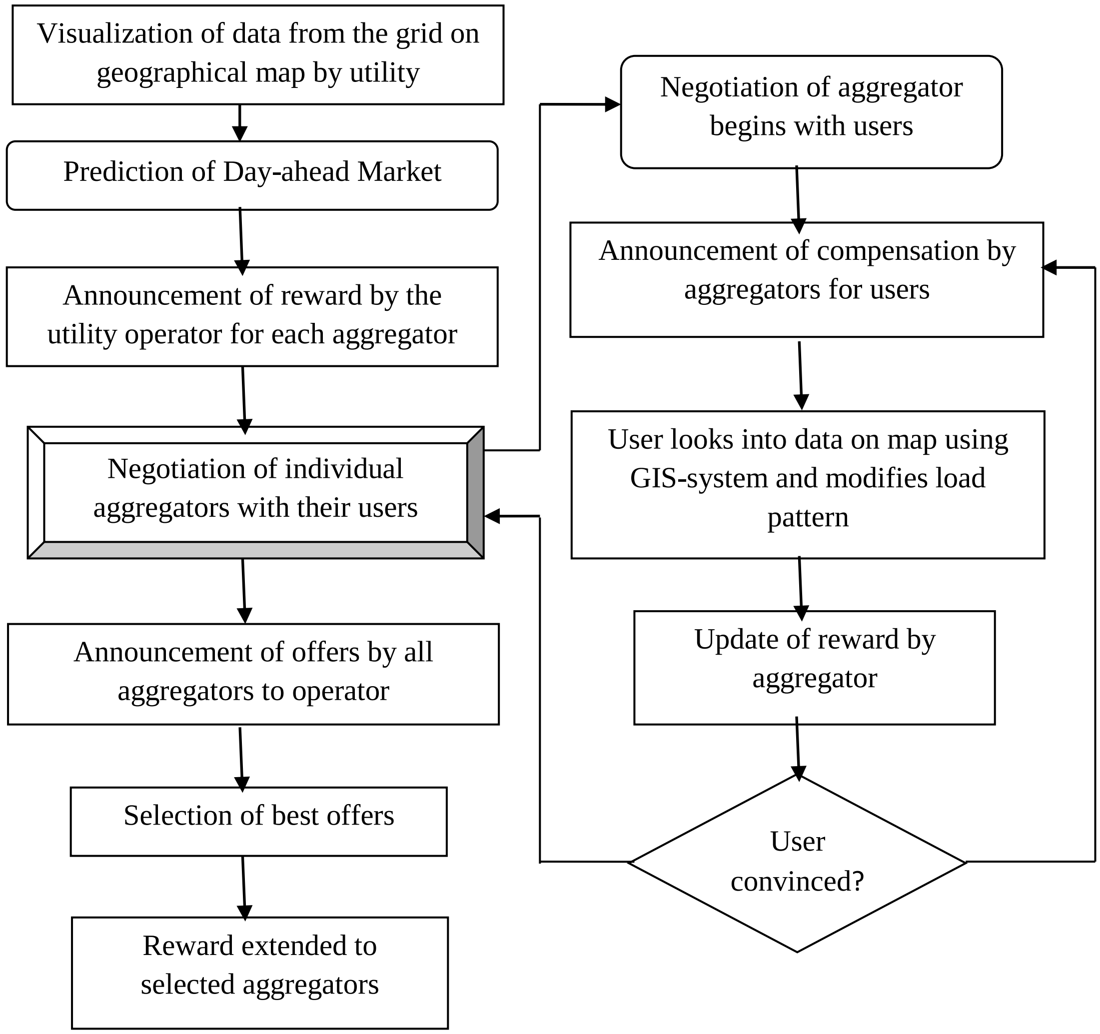


Figure 4.21. Flowchart to show the working of aggregator in a smart grid

Currently, the appliance scheduling game, as studied by many scholars, reaches optimality when Nash equilibrium is achieved for a non-cooperative scenario [104]. However, on studying viability of a non-cooperative game, as exists in modern day grids/Smart grids, observations have been made which suggest that a non-cooperative game suffers from many drawbacks such as unrealistic assumptions of unlimited computing ability, non-accountability of risks, infinite looping and most importantly, the Prisoners' Dilemma. To make the game cooperative the user at the lowest level needs to be aware of the status of the grid at any point of time.

Visualization is a powerful way to achieve this objective. A platform to show the current and predicted status of a grid makes it smart in terms of availability of information. GIS solutions provide an effective way of visualizing information at multiple levels. Also the architecture of layers makes it versatile in the sense of displaying information of multiple sorts.

According to [105], each appliance is an independent decision maker (or participant) which can start its execution by selecting the time for start. In case of appliance scheduling, one user is not aware of the strategy profiling of the other users. This may result in the haphazardness in the demand curve. Say let's consider a scenario when two users simultaneously switch on/off a particular appliance, then it may lead to extremities in the power demand and hence formation of deep crests/troughs in the demand response curve. This is the prisoner's dilemma in appliance scheduling. To overcome prisoner's dilemma it is necessary that the users are aware of not only their own strategy profile but also of their neighborhood. This is the scenario of a co-operative game. Since Nash Equilibrium is not Pareto efficient in case of prisoner's dilemma, it is suggested to use Sub-Game Perfect Equilibrium (SPNE).

Sub-game perfect Nash Equilibrium is a variation of the Nash Equilibrium and is recognized as application of Nash Equilibrium to atomize non-cooperative sub-games into a set of co-operative games [28]. This application of sub-game perfect Equilibrium resolves the lack of Pareto efficiency in Nash Equilibrium and suggests cost-minimization. Mathematically, it can be explained as below:

B= set of all appliances in a household

U= set of all users in the neighborhood

H= set of all households

UxB= set of all appliance ownerships possible

T= set of all time-instances

P_{nt}= power demand at time t for n^{th} house, where tϵT

P_{bnt}= power demand at time t for appliance b in n^{th} house, Where tϵT

P_{bT}= power demand for appliance b over T, where tϵT

C(.)= pricing function

π_{sL}= power supply limit in a day (power threshold)

I_n = strategy of household n

I= set of all strategy profiles of all households (set of I_n, n=1, 2, 3,………. N)

The load profile for individual devices at time tϵT, is given as

$$L= \{ L_{bt} : t\epsilon T, b\epsilon B\}$$

The cost function (which is to be minimized for optimization of the system) is given as:

$$\text{Cost (I)} =\sum_{n\epsilon N} \sum_{\substack{b\epsilon B \\ t\epsilon T}} P_{bnt} \,.\, C(P_{bnt}) \quad \text{for all} \quad t\epsilon T, n\epsilon N, b\epsilon B$$

Problem: The usage habits of the houses in a neighborhood are not known. Different households have different usage patterns leading to haphazard load profiles. There needs to be some communication existing between the households to synchronize their loads according to needs and time slots, in addition to lowering the slope of the demand curve.

Remedy: A cross product matrix of the households N, and appliances B, being run at time t ϵ T, has been devised to know all the possible strategies. Thus the strategy of household ‘n’ in the form of a matrix is defined as:

$$I_n = \left\{ x_n = \begin{bmatrix} x_{1n1} & x_{1n2} & x_{1n3} & \ldots & x_{1nT} \\ X_{2n1} & x_{2n2} & x_{2n3} & \ldots & x_{2nT} \\ X_{3n1} & x_{3n2} & x_{3n3} & \ldots & x_{3nT} \\ \vdots & & & & \\ \vdots & & & & \\ X_{Bn1} & x_{Bn2} & x_{Bn3} & \ldots & x_{BnT} \end{bmatrix} \right\};\ n \in N$$

Based on the above scenario, equation of sub-game perfect equilibrium is given as:

G: $\min S_n(I_n, I_{-n}) = \min S(I_1^*, I_{-1}^*) + \min S(I_2^*, I_{-2}^*) + \min S(I_3^*, I_{-3}^*) + \ldots + \min S(I_k^*, I_{-k}^*) + \ldots + \min S(I_N^*, I_{-N}^*)$

Here, each of the sub-game (S) is optimized, i.e. each sub-game is made to attain equilibrium, which automatically optimizes the overall game. The aim here is to optimize the cost function in each sub-game. The visualization of the user profile on the geographical map enables the users to analyze their current strategy, and hence reschedule their appliances as per the scenario, to form a new strategy. Change in strategy of the users is based on win-win situation at every micro level of the game, leading to co-operative optimization of the demand curve. In section 4.2, an optimization algorithm has been presented to optimize the demand response based on appliance rescheduling, depending on the priority of appliances and availability of energy. Here an algorithm has been designed, based on the SPNE proposed above, which includes the algorithm of section 4.2 for appliance scheduling in each household and also looks into the best electricity pricing available. Hence the demand curve gets optimized based on both appliance rescheduling and cost optimization. The flowchart for this algorithm is shown in figure 4.22.

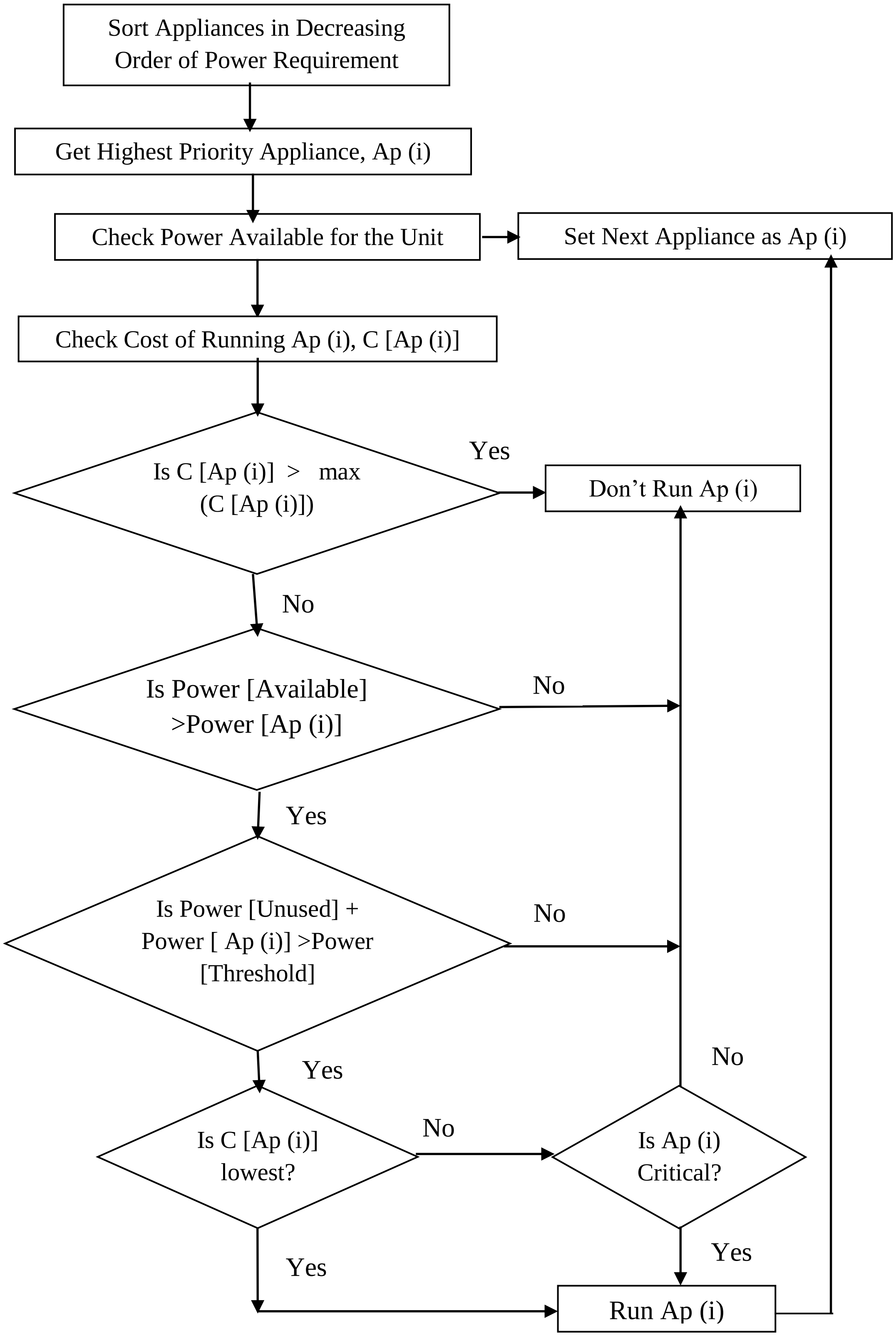


Figure 4.22. Flowchart to show the cost optimization technique while implementing demand side management in a residential microgrid

CHAPTER 5

IMPLEMENTATION OF DATA SECURITY IN SMART GRID WHILE USING GIS

The main objective of this section is to create a simple security system for a residential microgrid, which takes care of the privacy of customers and security of data. A small residential microgrid with 7600 houses (variation similar to that used in chapter 4.3) is created and the security system developed here is applied to it.

Earlier, without the use of data security entire pool of requested data was made available to any user upon a single click of mouse (as discussed in earlier chapters), which breached the data security and privacy of the customers in the residential microgrid developed here. Also the pool of data floated in the network while getting transferred from one point to other (server and dashboard). Hence this chapter presents a technique to overcome the above mentioned problems, allowing only registered members to view filtered data, depending on their level of access to the system. The level of access may vary from administrator to regular users. This system uses a basic cryptographic algorithm to overcome the problems of data security and privacy concerns in the residential microgrid.

5.1. INTRODUCTION

As the use of communication and IT infrastructure has increased in smart grid, the concerns related to data security and privacy have increased. Certainly, the grid has become more intelligent, but the threats to the critical and sensitive data have increased while it is stored on the server or while getting transmitted. Thus the data present on the server or in the transmission channel needs to be made secure from external attacks. Also, if the information of the users is leaked to external agencies or other users, without their consent, then the privacy of customers is at stake. To deal with all these concerns a method has been proposed in this section, which takes care of authentication of data and authorization of the customers.

The resources in the grid which are subjected to security and privacy issues include hardware resource, software resource, and geological data resource [106]. Out of all this data the most sensitive one is user's energy consumption information in real-time, as it can reveal a user's lifestyle to others. From the information collected by smart meters, complex usage patterns, such as residential occupancy and social activities, can be extracted without a priori knowledge of household activities [107]. Apart from privacy, data security is another issue of concern, as the system has threat from both internal and external attackers [108]. As per EPRI (Electric Power Research Institute), deployment of cyber security systems is one of the biggest challenges in smart grid [109]. The smart grid's security system must be able to handle the deliberate attacks such as those from unhappy employees, industrial surveillance, or terrorists, as well as handle the unintended compromises of the information infrastructure caused due to errors, natural disasters or equipment failures [110]. Third significant concern is data integrity, where the data is to be prevented from undetected modifications, by unauthorized persons or systems [111]. They attempt to corrupt the exchanged messages by different methods like false data injection. To overcome these issues some recommendations are available like documentation and auditing of information privacy and security policies, consent from customers for usage of information, collection of bare minimum data from individuals and so on. The other security concerns include authentication (confirming the identity of a user in the smart grid), authorization (preventing unauthorized users from entering the system), audit ability (ability to reconstruct the entire history of the system from historical records), trust, third-party protection, etc.

As mentioned in [28] and [32], the smart grid has a pool of data, which is present on the server. This data is crucial and needs to be secured from attackers for proper functioning of the grid in real-time environment. The data security applied to the grid information not only enhances the functioning of the grid, but also makes the various models and techniques acceptable. In this case, the main aim is to make GIS acceptable as a dashboard for displaying smart grid data over the geographical map.

5.2. SECURE COMMUNICATON OVER INSECURE CONNECTION

Any network has threat of various cyber-attacks such as eavesdropping, information tampering, altering of meter readings, injection of malicious control command, etc. [112]-[114]. A secure connection ensures safe and sound flow of data over a network without getting tarnished. A complete secure connection has the ability to protect information from getting viewed or tampered by external/unauthorized agents, prevent third party from getting access to confidential data and validate identity of users from accessing the system [115]. The method developed here looks into all three aspects mentioned above. There have been incidents which show that even a connection using security protocols (like HTTPS) does not provide complete security [116]. Hence the need of message encoding arises, which provides secure communication of data over a secure connection. Cryptography proves itself to be the best option for improvement in data (pricing information and control actions) confidentiality and security. Encryption happens to be a specific element of cryptography which hides information from malicious users by converting it into a code which is readable only by authorized users having authentic existence in the system [117]. The system here uses 3-way handshaking for establishing connection between two or more entities, HTTPS as the protocol for communication and transposition cipher for encryption of data/information (using SKC i.e. symmetric key cryptography).

5.2.1. 3-WAY HANDSHAKING

3-way handshaking is the method of establishing connection between local host and the server. With the use of three control messages, SYN (SYNchronized packet), SYN+ACK, and ACK (ACKnowledgement), this method establishes connection between two computers (local host/client and server) [118]-[119]. SYN bit indicates that the local host has initialized a connection establishment process. ACK bit indicates acknowledgement of the message received. SYN+ACK message indicates possession of both synchronization and acknowledgement bits. The client has no rights to perform any action until the server indicates an OPEN state, which means the server is ready to accept a connection. After the server performs a passive OPEN, a transmission control block (TCB) is created which means the server is ready to accept connection request from the client. Thereafter, the client creates a TCB for the connection and sends SYN message to the server and waits for a signal from the server.

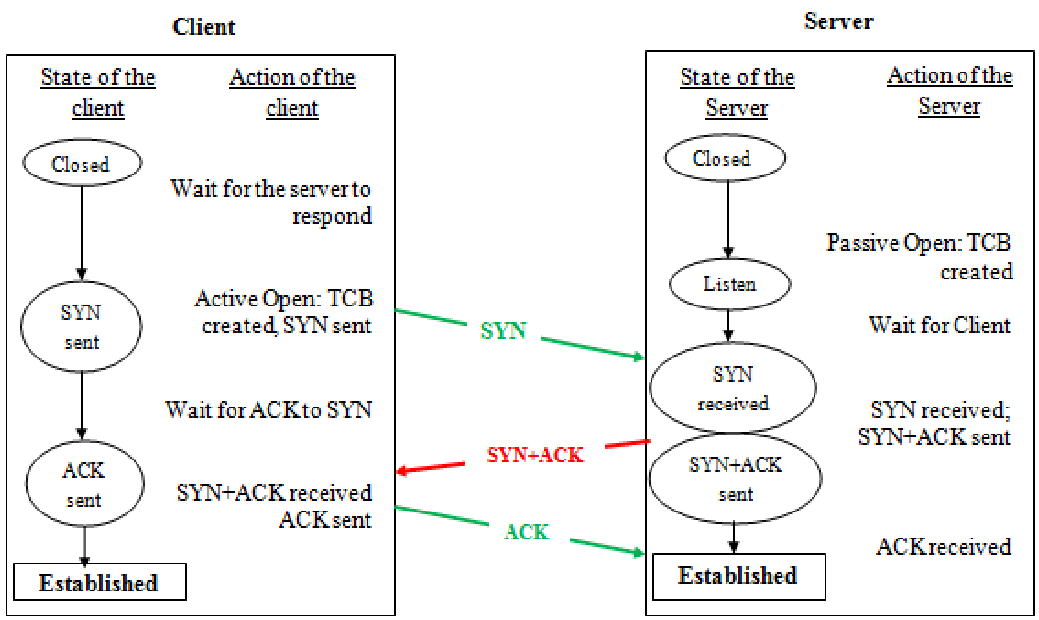


Figure 5.1. 3-way handshaking procedure

The server receives the SYN message from the client and sends a signal SYN+ACK back to the client. The client receives this message from the server and sends the acknowledgement with ACK message. Upon the server receiving the ACK message from the client, the connection is established successfully between the client and the server, thereafter facilitating the exchange of messages/data/information over the communication channel. Figure 5.1 shows the process of establishing a conventional connection between the server and the client.

5.2.2. HTTPS

It is also known as HTTP (Hyper Text Transfer Protocol) over TLS (Transport Layer Security), HTTP over SSL (Secure Sockets layer) or HTTP Secure. This protocol is used for secure communication over a network. The main motivation for HTTPS is authentication of website and associated web-server, including privacy and integrity of exchanged data. HTTPS creates a secure channel over an insecure network. The use of cipher suites along with HTTPS results in protection from eavesdropping and man-in-the-middle attacks, making it suitable to be used especially over insecure networks. The main purpose of SSL is to verify that user talks directly to the server and to ensure that only the server can read the content of the message being transferred [120].

When a user requests for a HTTPS connection to a desired webpage, the website first sends SSL certificate to the user's browser, which holds the public key for commencement of secure session. Then there is SSL handshake between the user's browser and the website (client and server) [121], and thereafter secure communication happens between the client and the server. The main benefits of HTTPS include safeguarding customers' information from getting intercepted by trespassers, authentication of the users and the websites, maintaining customers' faith in the system, and so on.

5.2.3. CRYPTOGRAPHY

Cryptography is the technique of hiding a message from getting accessed by unauthorized users or the public, with main objectives as information confidentiality/privacy, data integrity, non-repudiation of data and data/user authentication [122]. It enables the user to store and transmit critical data across insecure networks. In addition to data security cryptography is used for user authentication.

When the users need not take any special measure to read and understand data, it is known as clear-text or plaintext. When a cryptographic algorithm, called cipher is applied to the data, it becomes encrypted and is known as ciphertext. A cipher is a mathematical function which is used for encrypting and decrypting a message. The process of converting a plaintext into ciphertext is called encryption or encipherment and the reverse process i.e. to convert ciphertext into plaintext is called decryption or decipherment [123]. The processes of encryption and decryption are controlled by cryptographic key(s).

5.2.3.1.ENCRYPTION MECHANISM

There are three types of encryption/decryption mechanisms used for coding/decoding the message: secret (symmetric)-key cryptography, public (asymmetric)-key cryptography and hash function cryptography [124]. In Symmetric Key Cryptography (SKC), the secret key is shared between the parties to exchange messages. This key enables encrypting at the sender's end and decryption at the receiver's end. They use two types of ciphers namely stream ciphers and block ciphers. The ciphering algorithms include Data Encryption Standard (DES), Advanced Encryption Standard (AES), International Data Encryption Algorithm (IDEA), Rivest ciphers, etc. [125]. The main challenges here are to securely transfer the key to the receiver's end and prevent it from getting lost or stolen. The following figure shows SKC mechanism.

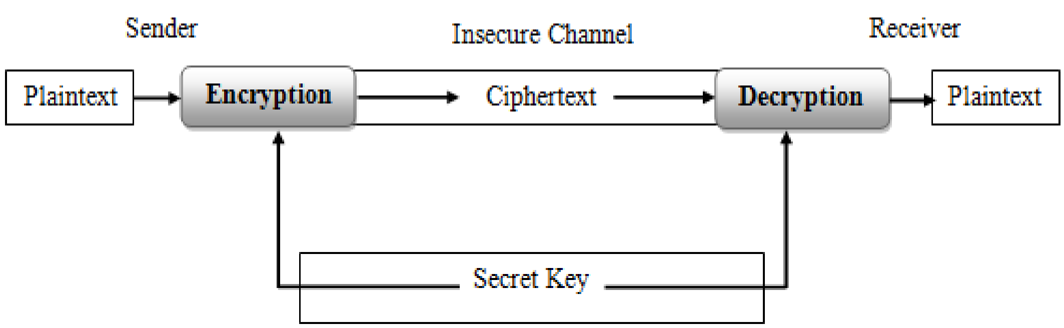


Figure 5.2. Block diagram for symmetric key encryption

Public Key Cryptography (PKC) is an asymmetric technique for encryption of a message where both public and private keys are used for encryption/decryption of message. The public key is used while encrypting the message while the private key is used for decrypting the message. This makes the message safe, as anyone can encrypt the message but only the person having the secret key can decrypt it. This avoids the unnecessary mechanism required to safely transfer the key from sender to receiver end as in case of SKC.

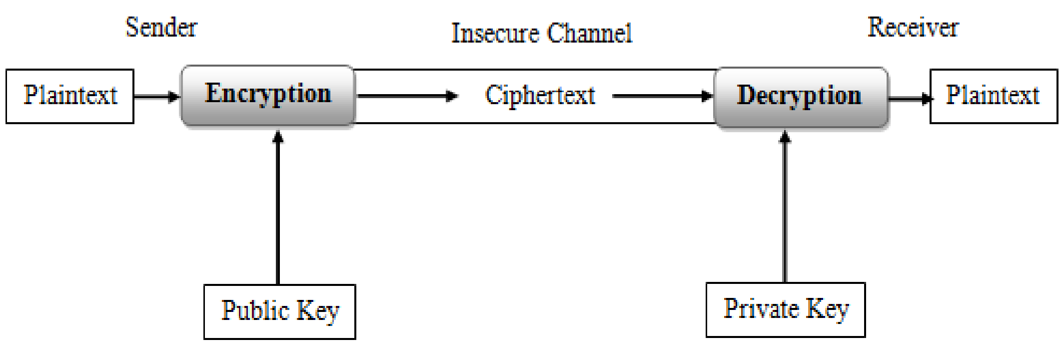


Figure 5.3. Block diagram for Asymmetric key encryption

Hash function algorithm maps an arbitrary amount of data taken as input into a fixed length output data [126]. The most visible property of hash functions is that it is impossible to determine the input by having knowledge of only the output. The output obtained after hash function to a message is known as message digest or hash values [127]. Hash functions offer many advantages over symmetric functions, the most important being faster computational speed. The popular hash functions include message digest (MD), secure hash function (SHA), RIPEMD, and whirlpool. They are used in critical applications like for storing password and checking data integrity.

5.2.3.2. TYPES OF CIPHERS

When talking about ciphers, they are of two types: substitution ciphers and transposition ciphers. Transposition cipher is the scheme of encrypting a message in which a rearrangement of the letter of plaintext is done as per the cipher key, hence the ciphertext appearing to be encrypted properly. There are various types of transposition cipher mechanisms like rail-fence cipher, route cipher, columnar transposition, double transposition, Myszkowski transposition, and disrupted transposition. Few of the transposition methods are discussed below.

In rail-fence transposition, the plaintext is split and written in zig-zag form depending on the number of rails, and then rearranged to form a specific pattern. For example, if the message, “WE ARE HUMAN BEINGS”, is to be encrypted using two rails, then it is done in the following way:

W A E U A B I G

E R H M N E N S

Plaintext : WE ARE HUMAN BEINGS

Compressed Plaintext : WEAREHUMANBEINGS

Cipher text : WAEUABIGERHMNENS

To decipher, the cipher text is divided into two halves and then it is rewritten with alternating letters from both the halves, as shown below:

String 1: WAEUABIG

String 2: ERHMNENS

Deciphered text: W+E+A+R+E+H+U+M+A+N+B+E+I+N+G+S

This decrypted text is then decompressed to receive the original text.

If the same string is to be encrypted using three rails, then the text is rewritten as shown below, and while decrypting the cipher text is broken into three substrings unlike two in the previous case, and one letter is picked from each of them subsequently.

```
W           E           A           I
  E     R     H     M     N     E     N     S
    A           U           B           G
```

Route cipher hides information by reordering the symbols in a message i.e. diffusion of symbols. This is done on the basis of key, which is distributed among the users. Only those users can read the decrypted messages that have access to this key. Let us consider an example.

Plaintext : WE ARE HUMAN BEINGS.

Encryption key : ENCRYPT

First the key is first ordered in alphabetical order, and then the entire plaintext is written accordingly as shown below:

E	N	C	R	Y	P	T
2	3	1	5	7	4	6
W	E	A	R	E	H	U
M	A	N	B	E	I	N
G	S					

The cipher text is thus written as:

1	2	3	4	5	6	7
A	W	E	H	R	U	E
N	M	A	I	B	N	E
A	G	S				

Then the remaining places are filled with alphabets in order as shown below

1	2	3	4	5	6	7
A	W	E	H	R	U	E
N	M	A	I	B	N	E
A	G	S	A	B	C	D

Thus the complete cipher text becomes:

AWEHRUE NMAIBNE AGSABCD

In case of columnar transposition, the same method as the above is followed, but instead of rewriting the text in row-wise manner, the rearranged letters are picked column-wise and rewritten. So the cipher text in case of columnar transposition becomes:

ANA WMG EAS HIA RBB UNC EED.

Substitution cipher is that technique of encryption in which certain units of plaintext are replaced with cipher text. The various types of substitution cipher mechanisms include mono-alphabetic substitution, homophonic substitution, polyalphabetic substitution and poly-graphic substitution [128]. In mono-alphabetic (simple) substitution, each letter is replaced by another letter and this replacement is fixed. For example, if 'b' is encrypted to 'X' then all appearances of 'b' in the plaintext will be replaced by 'X' in the cipher text [129]. Let us consider an example where the plaintext is "we are human beings". If the mono-alphabetic substitution cipher is the next alphabet of the one appearing in the plaintext, then the cipher text for the above message becomes "XF BSF IVNBO CFJOHT". The cipher text for 'w' is 'X', 'e' is 'F' and so on. In polyalphabetic substitution, a series of mono-alphabetic ciphers are reused periodically to create the cipher text. Homophonic substitution involves replacement of each letter of the plaintext by a group of other characters. Poly-graphic substitution makes it possible to replace a group of characters of the plaintext with another group of characters to create the cipher text.

5.3.SYSTEM DESCRIPTION

For the scope of this work, a residential microgrid has been designed in Matlab/Simulink comprising of 7600 houses in multiple neighborhoods. These houses are designed to follow the energy consumption pattern for the scenario of Singapore, with data for houses similar to what used in previous sections. The data obtained from the grid is saved on the data server for future use. This data/information is to be displayed on the ArcGIS/QGIS desktop which forms the presentation tier of the system. While travelling from the system to server or from server to the presentation tier this data has to move through the communication channel. The information related to the customers and utility providers like energy demand/supply, rate of electricity, available PV energy, etc. is very critical which floats on the internet, while being stored on the server or while getting transferred. This makes the information vulnerable to attacks leading to problems like breaching of customers' privacy; revealing customers' location, consumption pattern and distribution strategy; and so on. Eventually authorization of users and authentication of data become major challenges.

To establish connection between various nodes (client and server) 3-way handshaking is used. Data obtained from the grid is saved on the server in form of web pages (as it has to be displayed on GIS platform in the same format). To transfer this data from one point to another, HTTPS (HTTP over TSL) is being used, as it provides authentication of the website and the associated web server, which protects not only from external attacks while the data is being transferred, but also provides bidirectional encryption for protection against eavesdropping and corruption of data. In short, HTTPS creates a secure channel over an insecure network. For the purpose of data encryption, transposition cipher is used, which hides information by reorganizing the symbols in a message. Figure 5.4 shows the overall model of the system. As indicated in the figure, the system administrator has full access to the to the business tier, being responsible for setting/making changes in the authorization levels for the users; organization and management of data; and so on. The users who are authorized to the system have partial access to the system, depending on the degree of access they are extended by the administrator.

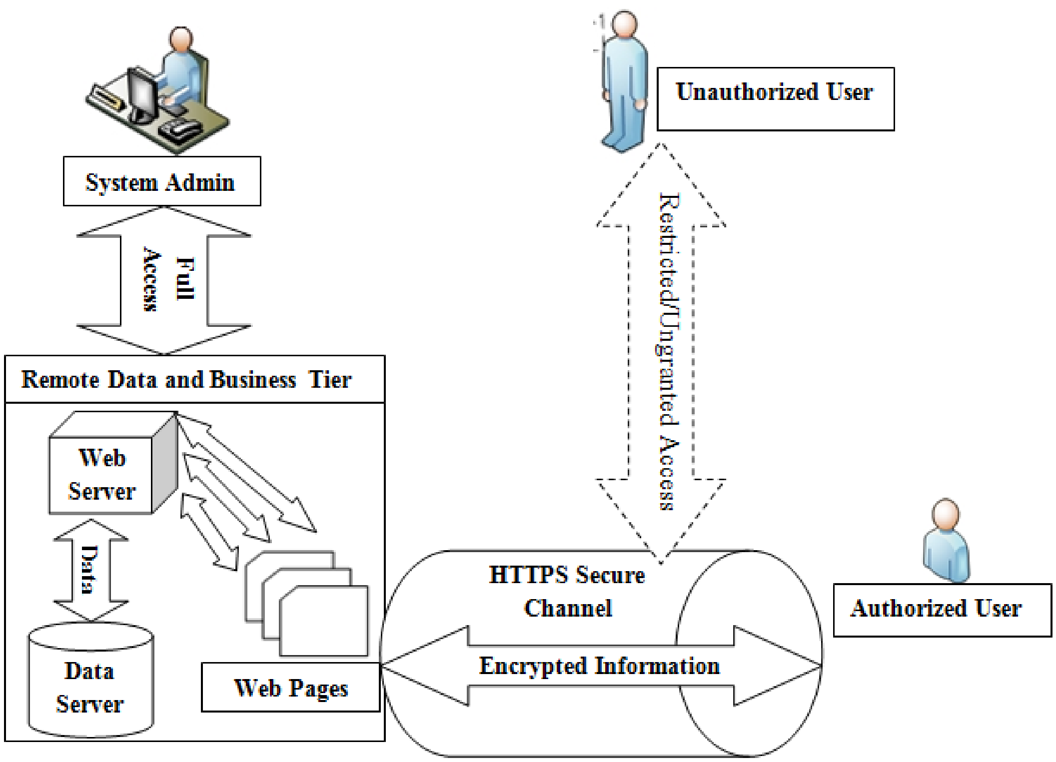


Figure 5.4. System Model for data security and customer privacy

For example, the registered users can view information of their own units and not of others; or they might have access to complete information of their own houses and restricted access to the energy flow information in their microgrid; or they might have certain level of access to the consumption details of public builds and so on. This right to view information completely depends on the requirements and privacy levels of the system. The information, which the registered/authorized users access, is encrypted while travelling over the transmission media. Any trespasser, who is not authorized by the system, cannot access the system.

Figure 5.5 shows the flow of information between various layers of the system. Upon accessing the GIS platform (presentation tier which forms the dashboard for users) the user places a request to get the desired information. If data security mechanism is not implemented in the system, then transfer of data takes place as shown in figure 5.5 by link 1 i.e. directly between the presentation tier and the data server. But this flow of information changes its path when data security technique is implemented.

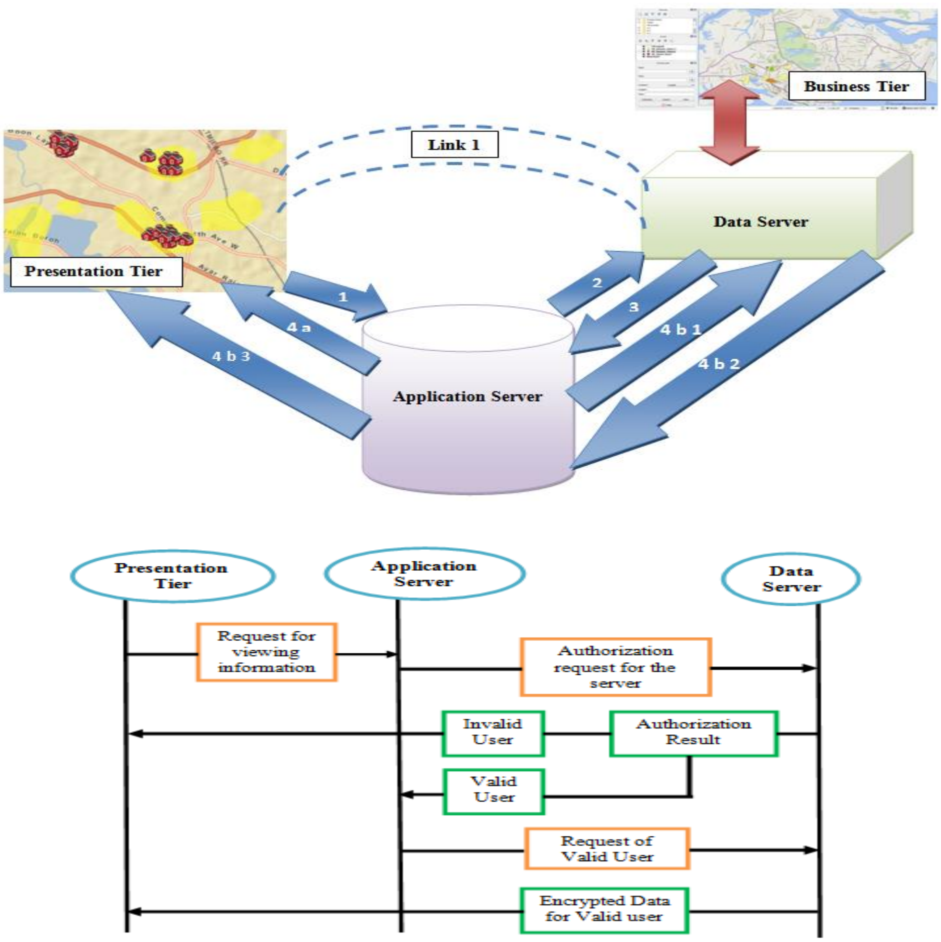


Figure 5.5. Flow of information and actions taken in the system

In the latter case when user places a request to view some information, it first goes to the application server which performs a task for authorization of the user, by asking the user to enter certain credentials in order to certify his genuine access to the system (username and password in this case). If these credentials match with the one stored in data server, then the request is forwarded to the data server. If the user fails to authorize him, he cannot move further to view the intended information. For successful authentication the request results of authorized user is encrypted using transposition ciphering method (having a cipher key) and is sent to the presentation tier, where it is decrypted using the cipher key and displayed on the dashboard in the same format as stored on the server. Here the information is obtained from the grid and stored in excel sheets, which in turn are stored on the server as web-pages in the excel sheet format.

5.4.SIMULATIONS AND DISCUSSIONS

The system discussed above is simulated, with some programs written and coded in python based on an algorithm discussed below. The algorithm includes establishing a secure connection, encrypting the request result and making the connection secure.

Algorithm: Secure Handshake

```
secure_handshake ()
{  establish_connection ()
{  check_connection()
{  If (connection=available)
    {    Create connection request, SYN
           Send SYN to server
      Gotoset_protocol ()
```

```
      }
     Else
    {  Check network status and prompt user
      Troubleshoot connection
      }
     Return to check_connection ()
   }}}
set_protocol ()
{  Communication_prototcol=HTTPS
send_request ()
   }
```

Algorithm: Send Secure Requests

```
send_request ()
{  secure_handshake ()
parse_request ()
  {   determine access level
   Make request for url
   Encrypt request
   Send encrypted requests
  }}
```

Algorithm: Serve Request

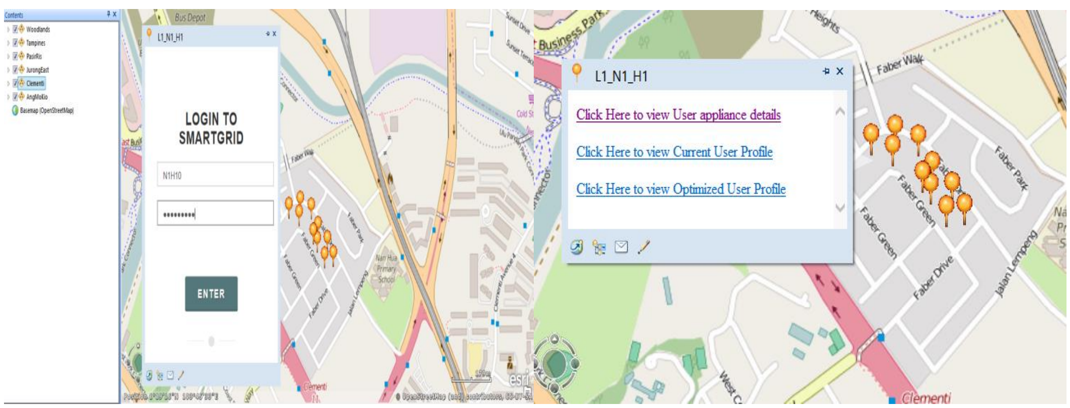
```
serve_request ()
   {   if (protocol=HTTPS)
   Receive request packets
   Else
   Drop connection
   Return ()
  }
If (serve_request())
{ if (encrypted message)
 Decryption ()
Else
  {   Read plain text
   Forward plain text to hander
  }}
```

As discussed in previous chapters, ArcGIS and QGIS can be used to visualize data on the geographical map. But the main concern remains security issues which have been dealt with in this section. A system for data security has been created which takes care of security issues in the process of visualization of data/information from the grid onto the geographical map. The data related to households and pricing is critical and has to travel over the communication channel which is generally insecure. Thus HTTPS has been used to make transmission of data over the channel secure. But there have been incidents which show that even while using HTTPS the data is not completely secure [130]. Hence the encryption method of transposition cipher has been used for secure communication over secure channel. For the scope of this work, QGIS is used in the business tier, for creation of shapefiles and logic. ArcGIS Explorer Desktop is used for presentation of data in real-time. Apache data server (Wamp) is used to store the information. As Python has been used for logic creation, thus Pychamp is used for implementation of this logic.

Earlier, without the use of data security entire pool of requested data was made available to the user upon a single click of mouse. Thus any user of the system could see the data pertaining to any other unit in the system. This breached the data security and privacy of the customers. But with the implementation of technique described here, these issues of security and privacy have been solved. While using this system, every user has to register with the system. One unit can have only one active user. Though single user can own multiple units but multiple users cannot register for a single unit. For the scope of this work each registered user is given the right to view information of only his/her house and not of others. The system administrator is given the right to view information of the entire system. These restrictions of viewing data can be varied depending on the requirements and users, while implementing it in the real system. Various cases for login have been discussed below in respect with the system developed here.

Case 1: User is registered; owns a unit in the system.
Result: Authentication and authorization successful; desired information displayed.

This is a case where the user owns a unit in the system and has registered for it on the system. In the presentation layer, upon clicking on a house on the map, user is asked to enter authorization details as shown in figure 5.6 (a). In this example, the user of Clementi area clicks on his own house named L1_N1_H1 and a window appears on the dashboard, where he needs to authenticate himself. Upon successful authentication, the webpage containing all the relevant information is downloaded from the data server into the presentation tier and it gets displayed on the map, in the same way as it happened in [28].



(a) (b)

Figure 5.6. Simulations showing screenshots of (a) login screen for L1_N1_H1, (b) webpage containing details for L1_N1_H1

The user can click on the links shown in figure 5.6 (b) and get the desired information. This information is initially stored in the data server. When user sends the query, first his authentication and authorization is checked. After getting success, the data on the server is encrypted using the cipher mechanism. This encrypted data having an encryption key is sent to the presentation tier via the application server, where it is decrypted using the key and the data gets displayed on the map.

Case 2: User is not registered or incorrect credentials; owns a unit in the system.
Result: Authentication failed. No need for authorization; information not displayed.

This is a case where the user owns a unit in the system and has registered for it on the system. In the presentation layer, upon clicking on a house on the map, user is asked to enter authorization details. But the user ends up entering incorrect details (username and/or password).

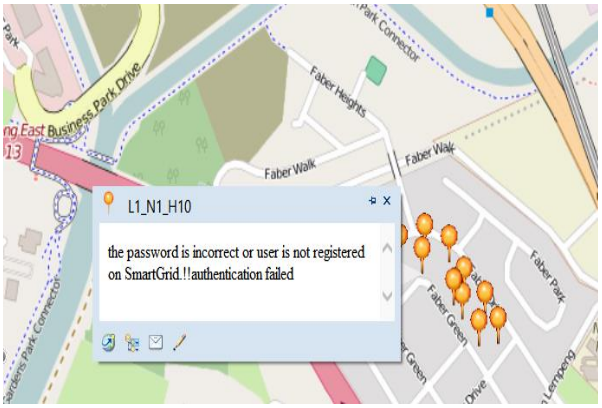


Figure 5.7.Error message for unauthorized user or unauthorized access.

Hence the user’s details are not authenticated by the system, and an error message appears on the screen. Eventually the user fails to view any information on the map even after being a genuine user. This can also be considered as a case of trespassing when a user from outside, who is not registered with the system, attempts to view the information of the grid. Any such user, who attempts to get access to the information of the grid, is directed to the error page, as shown in figure 5.7.

Case 3: User is registered; does not own a unit in the system.
Result: Authentication successful. Authorization failed; information not displayed.

This is a case when user registers with the system, but is not member of any house or unit. Upon entering the details when asked for, user gets directed to the error page as shown in figure 5.8. For example, if a user named “xyz” registers on the system with a valid password and tries to access information of house L1_N1_H10, he is directed to the error page.

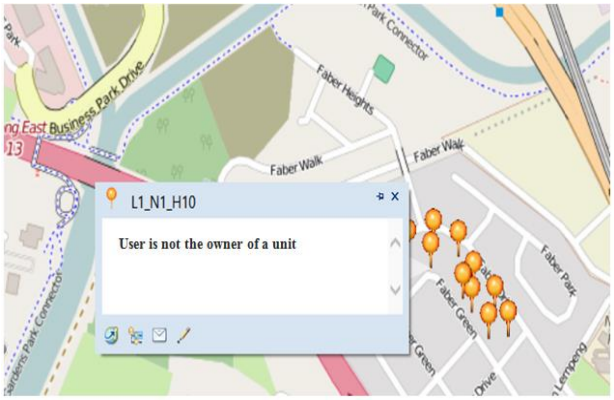
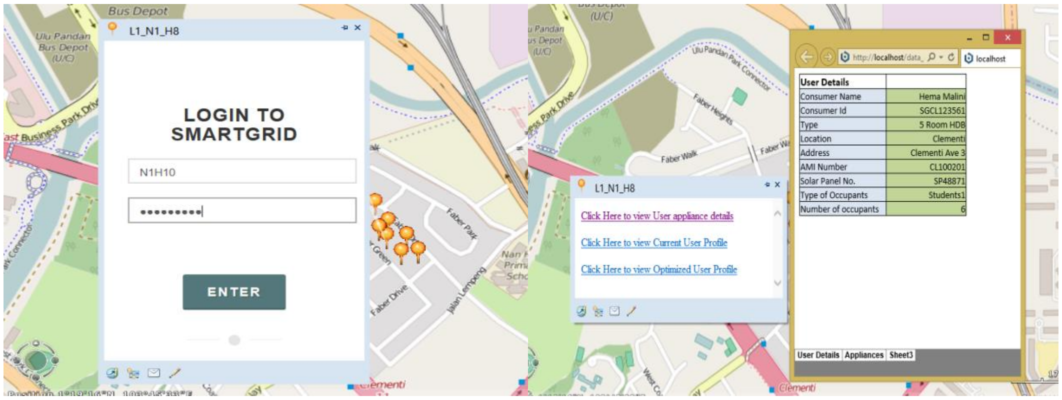


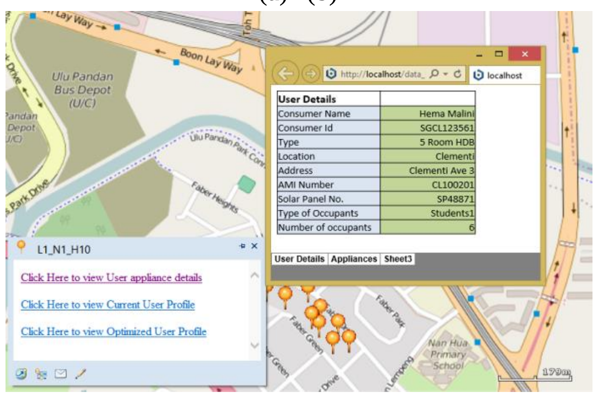
Figure 5.8. Error message for user who is not an owner of any unit in the system

Case 4: User is registered; owns a unit in the system; attempts to view details of others.
Result: Authentication successful. Authorization successful; information of his own house displayed.

This is a case when a registered user, who owns a unit in the system, attempts to view details of any other house/unit (which does not belong to him). There is successful authorization and authentication of the user and his details, eventually the information getting displayed on the dashboard. But this information is not of the unit clicked upon, but of the user himself. For example if the user registered with house L1_N1_H10 attempts to view details of house L1_N1_H8, then he is able to log into the system successfully and also is able to view information on the screen, but that data does not belong to L1_N1_H8, but it pertains to L1_N1_H10 only, as shown in figure 5.9.



(a) (b)



(c)

Figure 5.9. Screenshots of ArcGIS Explorer Desktop showing (a) login screen for house L1_N1_H10, (b) data of house L1_N1_H10 on clicking L1_N1_H8, and (c) data of house L1_N1_H10 on clicking house L1_N1_H10.

Though the system is effective enough as compared to one without data security, and has been tested for a small microgrid with 7600 units, but it has certain requirements. As for example, this system uses python for creation of logic, hence Pycharm must be in operation parallel to other sub-systems. Even if it closes for a moment, the system has to be reset else the presentation layer loses connection with the data server. The user encounters following error message if Pycharm stops/pauses and is not reset, as shown in figure 5.10. Also, there should be fast internet connectivity for effective working including data updating for the system in real-time. The results for this section have been tabulated in table 5.1.

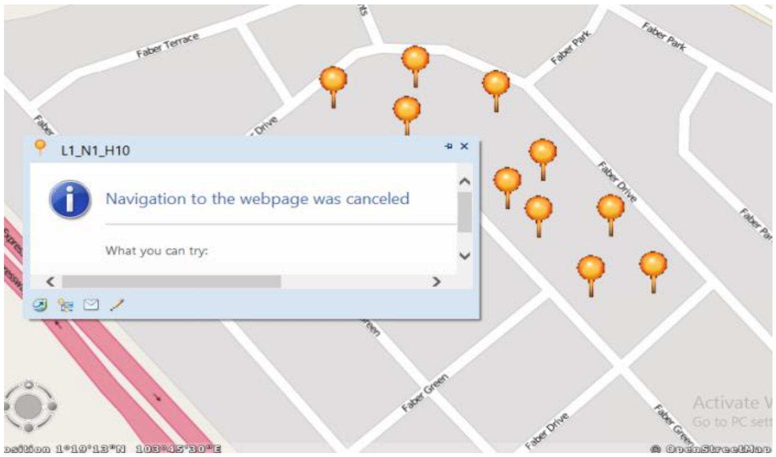


Figure 5.10. Error message when Pycharm stops

TABLE 5.1. RESULTS OF THE SYSTEM

Scenario		**Result**
Pycharm ON; Internet connected	Registered user owns a unit	Authenticated; Authorized
	Registered user does not own a unit	Authenticated; Authorization failed
	Registered user owns a unit. Views details of others	Authenticated; Authorized; Views own data
	Unregistered user	Authentication failed
Pycharm OFF; Internet connected	Registered user owns a unit	Navigation failed
	Registered user does not own a unit	Navigation failed
	Registered user owns a unit. Views details of others	Navigation failed
	Unregistered user	Navigation failed

The combination of QGIS and ArcGIS Explorer Desktop, as mentioned in [32] is perfectly suitable for the system. Use of Python for writing the code is more user-friendly and less complex, and as a matter of fact it is the most suitable language compatible with QGIS. All the software used here are easily available on the internet, which is a big advantage while creating a prototype of the system for testing purpose.

The authors of this paper have developed a system for data security for a residential microgrid comprising of 7600 houses. The problems associated with privacy concerns have also been dealt with in this work. This work is an extension to the work from the authors in [32]. The microgrid simulated is similar to that in [32], with more number of houses and featured with application server. The application server is responsible for setting up a secure channel for transmission of data and for encryption of the information which is crucial for the users and the grid. In future, the authors aim to add more features and levels of encryption for the data/information from the grid. The users could see more information apart from information about their own houses.

CHAPTER 6

RESULTS AND DISCUSSION

The main aim of this work is to show how visualization of data from smart grid on the geographical map using geographical information system (GIS) helps to enhance optimization of demand response and the cost of electricity for users. Various cases have been presented here to show how visualization convinces the users to adopt methods for optimization by portraying the grid data in front of them.

In the first part of this work, ability of the system to operate in real-time scenario has been presented. The system is designed using ArcGIS. A prototype of two houses has been created and this is linked to the data stored on server, coming from electric grid. On clicking on a house in the prototype of the system as shown in figure 3.4, the entire data related to that house gets displayed on the screen as shown in figure 3.5. To show the ability of the system to perform in real-time environment, the value of energy demand in 8^{th} hour of a day is changed from 12.196 to 16.87 on the server. This change gets reflected on the map the moment map is refreshed as shown in figure 3.6. a detailed discussion of the simulations and systems is presented in chapter 3.

Chapter 4 highlights the role of GIS to visualize information from grid on the map and use this for contributing to demand side management. Here instead on ArcGIS system, a hybrid of ArcGIS and QGIS is used, unlike in chapter 3. This chapter is divided into two sections. Section 4.2 describes how visualization of data from the grid makes the users participate in demand side management. The system is designed in a way so that every individual is able to see the details of his/her own house on dashboard and take actions accordingly. This section focuses on optimization of demand response. Once the users are able to see their own consumption pattern, they can reschedule their appliances for optimizing their demand curve. Though many optimization mechanisms are available for optimizing the demand response, but the best available algorithm can be used in the system.

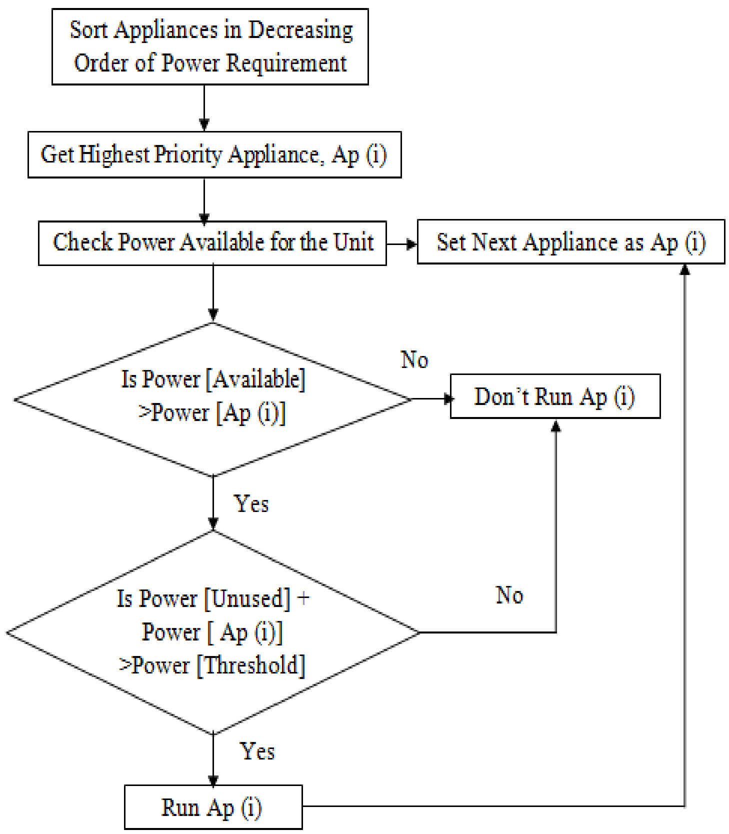


Figure 6.1.Flowchart to show rescheduling of appliances for optimization of demand curve

The author has designed an algorithm for rescheduling of appliances which has been given in section 4.2. This algorithm checks priority of appliances to be run before rescheduling them. The appliances are first sorted in increasing order of their priority and later depending on the available these appliances are given the command for operation, as shown in flowchart of figure 6.1.

When the user visualizes own data and participates in the optimization program, the demand response improves, hence contributing to demand side management. Figure 6.2 shows how demand curve changes after the user reschedule his appliances.

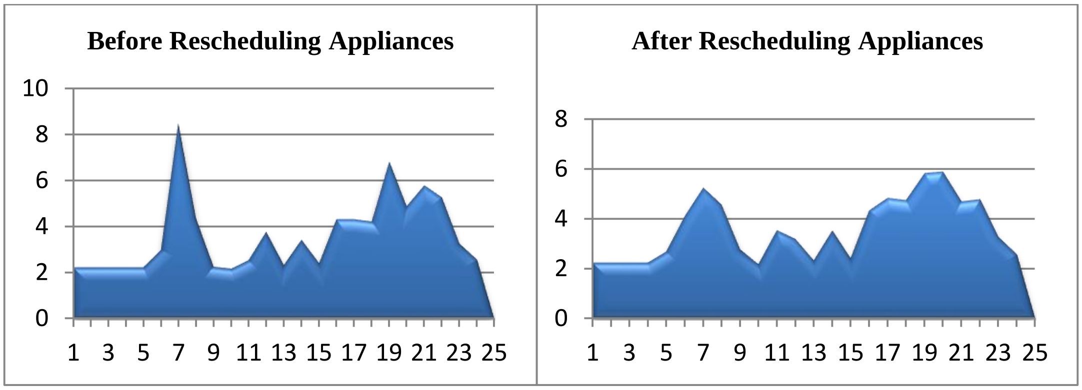


Figure 6.2. Visualization and rescheduling results in optimization of demand curve

Section 4.3 comprises of system which visualizes data at every level i.e. unit level, neighborhood level, microgrid level and grid level. This enables the users to see not only their own data but also the data of their neighborhoods and neighboring microgrids. This kind of visualization brings more transparency in the grid and makes the users aware of the various benefits and schemes available for them. In this section the author has talked about the role of aggregators and how they can be helpful in making a good negotiation between the users and the utility operator, making the users participate in various optimization (demand response, cost, energy, etc.) schemes, eventually contributing to demand side management. In this section the appliance scheduling has been considered as a cooperative game and each appliance is considered a unique player in the game. Here the concept of sub-game perfect Nash equilibrium is introduced which is denoted by following equation:

$$G: \min S_n(I_n, I_{-n}) = \min S(I_1^*, I_{-1}^*) + \min S(I_2^*, I_{-2}^*) + \min S(I_3^*, I_{-3}^*) + \ldots\ldots + \min S(I_k^*, I_{-k}^*) + \ldots + \min S(I_N^*, I_{-N}^*)$$

By optimizing each sub-game (S), starting from the user and extending till the grid, the entire game gets optimized. Here the aim is to optimize the cost of electricity consumption, by rescheduling the appliances.

As discussed in the previous section, visualization enhances the process of appliance rescheduling. Though there are many cost optimization techniques available from various researchers, but based on visualization, the author has presented a cost optimization algorithm as shown in the figure 4.22.

While using GIS as a visualization technique in smart grid, there arise concerns of data security and customer privacy. These issues are dealt with in chapter 5, where a simple system for authorization of users and authentication of data has been proposed. This method shows how to communication over an insecure connection in a secure manner using 3-way handshaking and cryptography. This system prevents unauthorized users from accessing the system. In addition, even those users who have access to their own system are unable to view the data to which they are not authorized to. This may be data of their neighboring units or the administrator. Only a person with valid identity and having valid login credentials can have access to information of ONLY his/her own unit. This has been clearly demonstrated in figures 5.6-5.9.

In [25], Sougata Mitra highlighted the role of GIS in smart grid in an efficient manner discussing about the various aspects like denoting the location of electrical infrastructure on geographical map, ongoing business processes, network connections, etc. He highlighted the fact that how GIS helps to optimize the demand

and manage loads, which eventually leads to lower cost of electricity and better efficiency of generation plants. He also discussed about the prospects of GIS being clubbed with SCADA for business applications. Though he highlighted all the facts of GIS for smart grid, but they all are restricted to enterprise GIS which cannot be used by every common man as discussed in earlier chapters. The use of open-source or hybrid GIS, as presented in this thesis, overcomes all the problems of proprietary GIS like license renewal, limited to experts, highly expensive, high maintenance, etc.

In [132], the role of aggregators for designing an effective demand response mechanism has been described. The authors have presented a scheme to maximize benefits of all the entities in the non-cooperative scenario where all the entities are self-centered as long as profit and benefits are concerned. But the author of the current thesis has presented an algorithm in section 4.3, where all the factors of [132] are taken into account like negotiation of aggregators with the utility operator, negotiation of the users with the aggregator, and benefits available to the entities of the grid, but with the visualization of information using GIS. Using the GIS system developed here, the users and aggregators are also aware of the current scenario (demand, energy availability, dynamic electricity pricing, etc.) unlike in [132] where only the utility operator has all the information about user demands. Also, the author has represented the optimization problem using Sub-game Perfect Nash Equilibrium (SPNE) where cooperation in appliance rescheduling results in optimization of the cost of every sub-game (appliance). This optimized cost is then used for scheduling the appliances appropriately for day-ahead market as shown in figure 4.22.

In [131] the authors have proposed a very effective scheme for network security using 4-way handshaking and the security protocols EMSA and SAE. Use of this system for HANs and NANs makes the network secure from cyber-attacks. But the use of 3-way handshaking, as done by author of this thesis, along with encryption using transposition ciphers serves a similar purpose of data security. The 3-way handshaking avoids one unnecessary iteration as in 4-way handshaking. As the message is encrypted using cipher key, hence there is no issue of loss of information even if that one ACK message is not sent from the server to the client, while the connection is getting established. The method adopted by the authors in this work is simpler and less complicated, maintaining the security levels required for a smart grid network.

This system which comprises of a hybrid of an open source GIS package and enterprise GIS, is regarded as an acceptable system because of following reasons:

Efficiency: It effectively helps in visualizing the grid data over the map, in the exact format as stored on the server without any delay or modification in the information.

Reliability: This system proves itself to be reliable as original data is made available to the users without getting tampered or stolen, because of the security system presented in chapter 5.

Speed: As the data is organized in the form of layers, hence the time taken to download desired data from the server on the map becomes smaller as compared to a system when the entire data is downloaded on the map at once without any use.

Rapid recovery: The system becomes dormant in the absence of internet, but as soon as the network resumes, the entire system, including the security system resumes immediately, without harming the data or the system.

Cost effective: The use of open-source software makes the test-system cost-effective and affordable to every user who wants to use this system. Also, no maintenance charge is incurred as in case of enterprise GIS.

User-friendly: The system is interactive and the applications are self-illustrative. Due to presence of the GUI interface, it becomes easy for the users to make efficient use of this dashboard.

CHAPTER 7

CONCLUSION AND FUTURE WORK

In this piece of work the role of Geographical Information System (GIS) for visualizing information from the grid has been discussed. The highlights of this work include:

1. Development of a GIS-dashboard prototype (with two Singaporean houses) using ArcMap and ArcGIS Desktop Explorer, and its ability to operate in real-time environment, as discussed in chapter 3.
2. Development of a GIS-dashboard using a hybrid of QGIS and ArcGIS, for small-scale residential microgrids (simulated in MATLAB/Simulink) and its ability to use the visualization of data for optimization of demand curve.
3. Development of a system to solve the issues of data security and customer privacy.

Though a remarkable amount of work has been done as mentioned in this dissertation, but still there is still a wide room for improvement, a few of which have been mentioned below:

1. Here only the basic appliances powered by grid electricity have been included and the DERs (like solar, wind, EVs, etc.) have been ignored, which can be added in future.
2. The system can be developed and programmed in such a way that selected houses of a given microgrid, or selected microgrids can be chosen to display the

data, unlike of all the houses of a microgrid, or of all the microgrids altogether as done in section 4.3.

3. A lot more can be done with data security system like the restriction to view data can be varied depending on the type of login, part of data made available to the users can be changed, customers can be given rights to set level of security for their own data, and so on.

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