UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING


# DYNAMIC MODELLING, MAPPING AND GRAPHICAL DISPLAY OF AN ELECTRIC POWER NETWORK

PROJECT NO: **PRJ031**

By


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Project report submitted in partial fulfilment of the requirement for the award of the degree of

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**Department of Electrical and Information Engineering**

**Declaration**

I, Rajab N Said, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

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**Name of Student**    **Signature**    **Date**

This project has been submitted for examination with my approval as University Supervisor.

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**Name of Supervisor**    **Signature**    **Date**

## Abstract

The electricity sub-sector in Kenya is no different from other sectors as far as its operations are concerned—traditional planning, operation and maintenance of the power system network assets is not only manual but also has flaws such as difficulties in searching previous records and updating them, which is a very time consuming task. The main objective of this project was to dynamically model, map and graphically display an electrical power network on the Web. This involved the creation of a web interface that allows a user to build a dynamic database of power network assets from which the generation, transmission and distribution of electric power can be mapped. A dynamic database was created for generators, transformers, substations, and power lines, which stores the important information for decision making, future planning and analysis such as location of faults and electric breakdowns, or load on a particular generator or transformer. Using a dynamic Web interface together with Geographical Information System (GIS), the data in the dynamic database was overlaid on the existing base map of Kenya with the facility for zooming, resizing and scrolling. Online mapping and access of the electricity network on a web map can help us plan for new power lines and extensions, preventive maintenance, easy retrieval of records, avoiding site surveys for new connections and improved asset management. Users can easily access the power network assets' information at the comfort of their internet-connected computers or mobile phone devices.

**Dedication**

This project is dedicated to my family for their support and encouragement in my pursuit of the Bachelors Degree.

**Acknowledgement**
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**Acronyms**

| | |
|---|---|
| KPLC | Kenya Power and Lighting Company Limited |
| KETRACO | Kenya Electricity Transmission Company |
| KenGen | Kenya Electricity Generating Company |
| REA | Rural Electrification Authority |
| GIS | Geographic Information System |
| GPS | Geographic Positioning System |
| PC | Personal Computer |
| MW | Mega Watt |

# Chapter 1: Introduction

## 1.1. General Background

An electric power network basically means the apparatus, equipment, plant and buildings used to convey, and control the conveyance of, electricity to consumers [1]. The electrical power network involves the generation of power, then transmission and finally distribution of the electric power to consumers. These three areas have seen tremendous growth over the last decade in line with Kenya's Vision 2030. According to KPLC's 2014/2015 Annual Report, Kenya had a total installed power generation capacity of 2,299 MW or 0.49 kW per capita as at the end of June 2015; this has grown from an installed capacity of 1,896 MW as at the end of June 2014. The total number of customers stood at 3,611,904; this is after connecting a record 843,899 new customers during the year 2014/2015, thereby raising the country's electricity access from 37% to 47% as at end of June 2015 [2].

In Kenya, electrical power is generated at between 3.3 kV and 11 kV. Transmission of electricity is done at high voltages, i.e., 132 kV, 220 kV and 400 kV. Distribution is done at medium and low voltages, i.e., 66 kV, 33 kV and 11 kV, and finally stepped down to 415 V (three-phase) for connection to consumers. The Kenya National Grid is operated as an integral network linked by different voltage-level transmission and distribution networks. The National Grid greatly impacts on the future growth of the energy sector because any new generation capacity must take into consideration the existing network and its capacity to handle new loads.

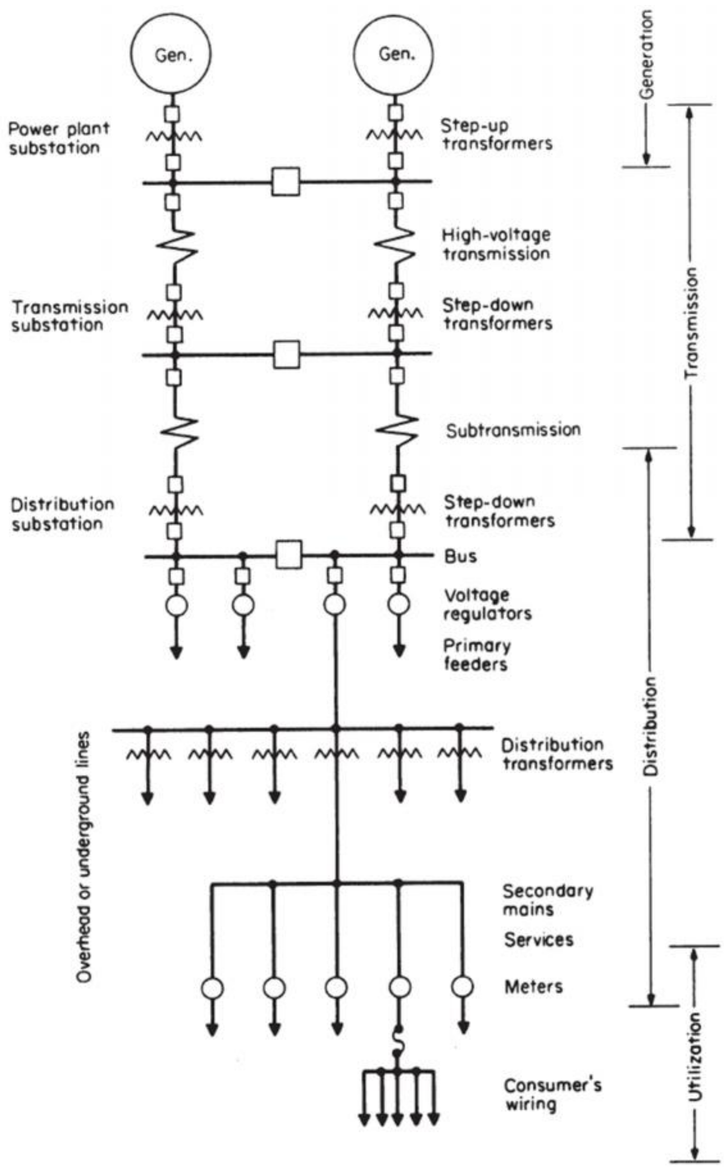


**Figure 1:** Typical Electric Power System

Over the last few decades, the energy sector has installed new power plants, substations, new transmission and distribution lines in a bid to keep up with the rapid growth of power demand. However, this has not been an easy task; availability of land for new substations and suitable routes for new power lines have been restricted due to development of rural areas and the growing concern over environmental effects of electric power. The Government of Kenya has now embarked on a 5000+ MW program that aims at delivering new generation infrastructure to eliminate the current supply deficit while also providing new generation capacity to support the Vision 2030 program. The power utility sector, in line with this program, focuses on increasing the customer base, increase grid coverage and improve the quality of power supply.

It must be stressed that efforts must not only be made to maintain efficient power generation, but also to transmit and distribute generated power with minimum possible losses. Efficient consumption of the generated power can be achieved only with appropriate record keeping and keen observance of the generation, transmission and distribution system. According to Pickering, "any organization that expects to run an efficient day-to-day operation and to manage and develop its services effectively must know what asset it has, where they are, their condition, how they are performing, and how much it costs to provide the service" [3]. In a bid to make informed decisions regarding to the planning, operation, maintenance and growth of the electrical power network, there is need to collect and fully analyze information regarding it. This not only results in efficient delivery of power to consumers, but also in the operation and maintenance of the network assets, and in sensible planning of new works and line extensions.

## 1.2. Problem Statement

The electricity sub-sector in Kenya has long been facing serious problems of electricity generation, transmission and distribution. Balancing the need to develop new generation plants, new markets, improve system reliability, and reduce operation costs is the greatest challenge for today's power utility decision makers. Across the entire sub-sector, applications in business, engineering, environmental management, and other disciplines necessary for comprehensive and effective power generation and transmission management have faced a myriad of challenges. Sophisticated spatial network analysis has been rendered difficult due to lack of integrated spatial data and information. This has led to great challenges in planning and monitoring of power generation resources, determining optimum generation potential, analysis of growth opportunities for renewable energy sources, formulating what-if scenarios, studying environmental impact of electric power, and managing network assets. Power utility companies have also been facing difficulties when they need to spatially analyze network congestion and determine site feasibility.

Kenya's Vision 2030 program is very ambitious and outlines major steps to grow the power sector with the aim of increasing electricity generation, transmission and distribution efficiency, and connection to consumers. But, as this is envisaged, there still exists several key shortfalls in the power sector with regard to the operation and maintenance of the already existing power network. At KPLC, for example, information on distribution and consumer electricity connections is not integrated; maps of the electrical network, network assets' data are in different files and even different cabinets all together. The rate of connection of power consumers to the National Grid has surpassed the rate at which the network base maps are updated. This results in disparity between what is actually in the field and what exists on base maps. At KenGen, data on power generation assets and generation analytics are in different files. Data on load growth and changes in load shape is not integrated. In addition to this, crucial information on potential generation sites is not readily available. This lack of integrated information poses great challenges with regard to:

i. Planning and monitoring of power generation resources, and analysis of growth opportunities for renewable energy sources,
ii. Planning, design and construction of new works and line extensions,
iii. Efficient power network maintenance,
iv. Quick connection of new customers,
v. Effective emergency response to electrical breakdowns or faults,
vi. Selection of short and economical routes for supply of electricity, and
vii. Easy access to information by power utility companies' employees, power network planning agencies, power consumers, and the general public.

A potential solution to this involves the design of a web-based application that allows a user to build a dynamic database of the electric power network assets from which the entire power network from generation, transmission and distribution can be mapped online (displayed graphically on a web map). This allows for complete integration of the network assets' data in a single database for easy access. According to Buckley, "a web map is a map and related content presented in an online environment with an appropriate interface and optional functionality for queries and reports"[4]. With the use of Geographic Information System (GIS), effective mapping of all network assets can be done.

Geographic Information System (GIS) can be considered, in one way, as a technology that helps us design, store, retrieve and manage spatial data [5]. With it comes the facility to map the complete electric power network, its assets such as generators, transformers, substations and customer supply points with spatial locations overlaid on other map layers or satellite images. This results in an electrical network map with a lot of its information stored in layers. For instance, the first layer can correspond to the electrical power network coverage, the second layer can contain roads and buildings and the third layer can contain information on the network assets, i.e., generators, transformers, substations, conductors and circuit breakers. Most of the electrical network assets have a geographical location and its full benefit can only be acquired if the work is done in the geographical context. For instance, if we want to add a new electricity connection to the system, it must be known and ensured that no one will be affected by this addition and GIS can do this effectively [6]. In the words of Dangermond, "GIS models the utility infrastructure. It captures the inventory of assets, their location, their condition and relationships of assets to each other and to their surroundings"[7]. In order to minimize operational costs, the power utility companies can integrate GIS with GPS to help in collecting information about utility facilities, without necessarily having to send a surveying team to the site to locate utility equipment and then transfer it on the map.

Databases can store and maintain large amounts of data, which can be retrieved with a single click. With the help of a relational database management system that can store, modify, link and retrieve various data of the power system network, analysis can be much simpler. The GIS database consists of the map data, i.e., spatial data (longitude and latitude) describing the location of geographic objects, and attribute data, i.e., non-spatial data describing the physical characteristics of each object. Appropriate analysis of this information makes it easy to locate faults along the power line and rectify them in the shortest time possible. Once databases have been created, they can be used for analysis and modeling of the electric power network.

GIS enables this data to be extracted, joined in new ways, and graphically displayed as preferred by the user [6].

Effective web mapping of the network assets makes it easy to make textual queries to retrieve useful information for various business processes. For example, consider the power utility's planning department is asked to supply power to a target area by installing a new facility and routing electricity to it. Obviously, it is more cost-effective to install a facility that is in close proximity to the target area. If the planning department wants to determine the power need for the new area, it can access the network's database information through the web map. The user enters the location of the new area and performs a distance query such as the location of all 132-kV transmission lines within 100 kilometers of the site. GIS produces both a map and a list of those transmission lines.

## 1.3. Objective

The main objective of this project is to dynamically model, map and graphically display an electrical power network on the Web.

### 1.3.1. Specific objectives

i. To create a web interface that allows a user to build a dynamic database of power network assets from which the generation, transmission and distribution of electric power can be mapped.

ii. To build a dynamic database consisting of all the generators, transformers, substations, transmission lines, distribution lines and circuit breakers, and their attributes from which power network data can be accessed in real time.

iii. To use the assets' data in the database to map and graphically display, online, the location of each asset (with its attributes), all this being done on a user-friendly Web interface.

iv. To provide a web-based platform for collaboration and data sharing between electric utility companies, power network planning agencies and power consumers.

## 1.4. Project Justification

With the ambitious Vision 2030 program, the power sector is growing so fast by the day. In terms of infrastructure development, new generation plants, substations and power lines are being installed at a very fast rate. The rate of connection of power consumers to the National Grid has surpassed the rate at which the network base maps are updated. This results in disparity between what is actually in the field and what exists on base maps, thereby leading to poor and misinformed decision making. The present day power utilities make use of digital maps and analog maps (paper maps and atlases). Even though digital maps involve a computer, these maps may not be accessible through the internet. With such maps, the operator needs to be at the place of work with a computer on which the software is installed. Furthermore, people in the office cannot coordinate with remote teams.

Web maps can effectively address these drawbacks. They can be readily updated so as to capture the actual information in the field as the network map is updated frequently at the same rate as the rate of connection of power consumers. Moreover, with a web map the power utility companies, their employees (more importantly the field personnel) and power consumers can easily access the same map-based information using smartphones, tablets and PCs, thus making it easy for people in the office to coordinate with remote teams. Office personnel can also assign work packages to field teams, with remote users receiving these alerts on their smartphones and tablets. To access the network database by the user, only a web browser and access to the internet is needed.

### 1.5. Scope of Work

This project aims to create an online power network map. Concentration is on mapping the generation, transmission and distribution assets on an online environment for easy retrieval of asset information. The project aims to embrace and utilize the geographic information system in electrical power network by incorporating a geographical context in the network assets data.

# Chapter 2: Literature Review

### 2.1 Present Power Scenario and the Web & Internet

The Electricity sub-sector falls under the Ministry of Energy (MoE), which provides policy direction. The Energy Regulatory Commission (ERC) is responsible for formulating and enforcing regulations, licensing power companies, providing customer protection, approving power purchase agreements (PPAs) and conducting tariff reviews. Kenya Electricity Generating Company (KenGen) is the largest power generating company and is majority government owned. The remaining grid-connected generation is provided by privately owned independent power producers (IPPs). The Geothermal Development Company (GDC) develops geothermal steam fields for subsequent use by generation companies. Kenya Power and Lighting Company (KPLC), which is 51 % government owned, owns and operates both the transmission and distribution networks throughout Kenya. KPLC is responsible for purchase of all bulk electricity and is the sole supplier to end-use customers throughout the country. KPLC also operates the majority of the off-grid diesel power plants on behalf of the Rural Electrification Programme. KPLC is the system operator and is responsible for generation scheduling and dispatch, frequency control, voltage control, outage management and system security. Generation dispatch and control of the transmission network is via the national control centre (NCC). The distribution networks are controlled regionally though each of the four regional control centres (RCCs). Kenya Electricity Transmission Company (KETRACO) is 100 % government owned, with responsibility for constructing new transmission lines across the country and then handing them over to KPLC to operate and maintain.

The Electricity Sub-Sector's first Medium Term Plan 2008-2012 envisaged a national installed power generation capacity of 3,000MW by 2018. The electric power is generated from various sources with their respective contributions shown in Fig. 2 below. The total installed power generation capacity stood at 2,299 MW while the peak demand stood at 1,512 MW as at the end of June 2015. A total of 402.7 MW was added during the same period as part of the planned 5000+ MW additional generation capacity. This additional energy capacity comprised of 225 MW of geothermal, 157.32 MW of thermal and 20.4 MW of wind power. During that period, the total energy loss was roughly 18 per cent of the total energy purchased by KPLC. Based on the demand projections made by KPLC, the Government of Kenya has capped a capacity addition target of 5000 MW by 2018 so as to bridge the gap between demand and supply. An integrated approach, including capacity addition through nuclear and non-conventional energy also has been planned. Currently, the power supply in Kenya can be described as 'inadequate and unreliable'.

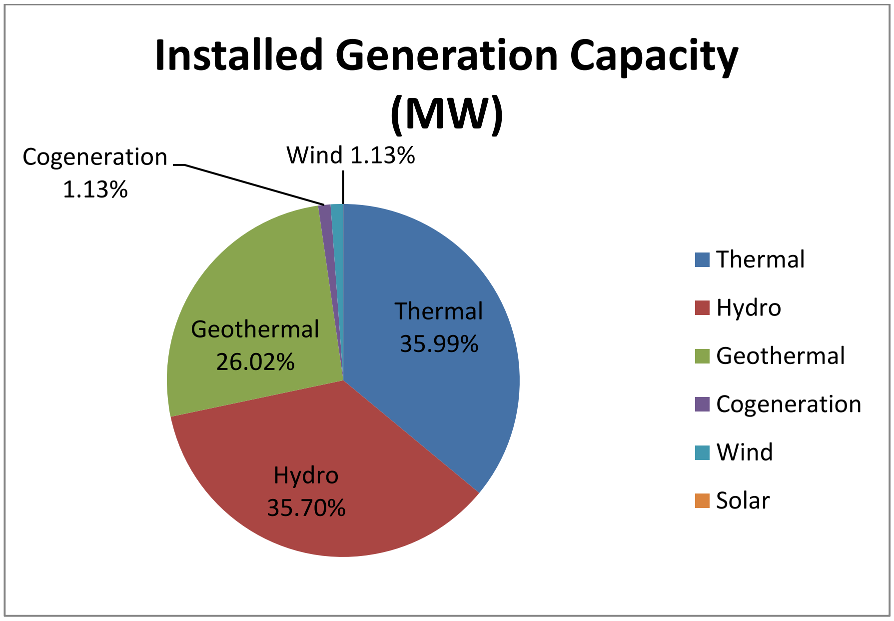

**Figure 2:** Energy mix by source (*Source*: KPLC Annual Report 2014/2015)

The major reasons for inadequate and unreliable power supply are:

a. Inadequate power generation capacity
b. Inefficient utilization of the existing generation capacity
c. Inadequate and ageing transmission and distribution network
d. Large scale theft and vandalism
e. Inefficient use of the electric power by the end consumer

The tremendous growth in popularity of the internet and the growing public interest in accessing online electric power network (with spatial dependency) information have brought an inevitable need to develop web mapping applications. As a matter of fact, in many Kenyan Universities, the development and usage of Web applications is one of the most popular directions of research and development in the field of Information Technology (or Software Engineering).

The web is playing a huge role in spatial application development mainly because of advantages such as platform independency, reduced maintenance problems, ease of use and widespread access. The most important power of web-based spatial application is the ability to publish and share geo-spatial information on the web thus allowing information to be exchanged in a rapid and efficient manner.

In Kenya, there is a growing need for digitization and online display of the electrical power network so as to address multi-disciplinary issues with spatial dimensions. Because most of the electrical network assets have a geographical location, then the full benefit of this new development can be achieved only if the work is carried out in the geographical context. Web-based geographic information systems result in easy and fast dissemination, sharing, displaying and processing of the spatially-attributed network's information which in turn helps in effective future planning, maintenance, upgrading and management of the power network.

## 2.2 Mapping Application Architecture

### 2.2.1 The Database

Geographic data services via internet require proper management of spatial and non-spatial data. Spatial data attributes can be effectively managed using Object Relational Database Management Systems (ORDBMS) which, in most cases, are open-source [8]. A quick survey on various database management systems available shows that PostgreSQL is one of the most popular object-relational database management systems (ORDBMS) on the open-source platform that can be used to store and efficiently analyze spatial data. It is released under an MIT-style license and is thus free and open-source software. It has powerful indexing mechanism and supports various data types and user-defined objects. The pgAdmin, a graphical front-end administration tool for PostgreSQL has made the overall management of the database easier.

It is not easy to store the spatial data in a standard RDBMS, thus spatial extensions have been developed and standardized by the Open Geo Consortium (OGC). PostGIS, being open-source and OGC compliant, is used as a back-end spatial database extender for PostgreSQL. It adds spatial function and special geometry data types to the PostgreSQL object-relational database. It is an excellent way to bring spatial and non-spatial data together into a common management environment. The conversion of shapefiles to PostgreSQL database tables is achieved using the shp2pgsql utility included as part of the PostGIS extension. This utility takes a shapefile and outputs a series of SQL statements to create a table in PostgreSQL database. The resulting table contains all the attributes of the shapefile including the coordinates that define each feature [9].

### 2.2.2 The User Interface

Web applications for the power network support the interaction between different parties participating in the generation, transmission, distribution and consumption of electric power, and also effective management and maintenance of the network assets. A power network assets' web interface allows the administrator to add/update assets (or assets' attributes), i.e., modify the network's database. It allows other users to view the power grid by sending requests to the web server which then returns the requested information on a map displayed on the web page. It can also provide the user with the facility to print the web page containing the map.

For better usability, a good web interface and web map should present the following factors to the user:

i. Adding/updating an asset and confirming the change on a map.

ii. Knowing the total number of respective assets (e.g., generators, transformers, substations, etc.) on the power grid.
iii. Determining the best route for a new power line or checking the nearest and convenient connection point for purposes of power connection to new customers.
iv. Simple navigation between the home page and the web map.
v. Displaying the asset's key attributes using an information window or popup when the asset is clicked on the map.

### 2.3 Web GIS and Power Distribution

Web GIS is a combination of the Web and Geographic Information Systems. Web GIS started in 1993 with the development of a web map by the Xerox Corporation Palo Alto Research Center (PARC). The most common function of Web GIS is web mapping where GIS data and analysis are presented in the form of web maps. The Web and Internet have allowed direct and real-time access to information from cyberspace without regard for physical access location. This gives Web GIS the following advantages over traditional desktop GIS [10]:

a. *A large number of users*: Web GIS can support multiple users concurrently unlike the traditional desktop GIS application which is used by only one user at a time.
b. *A global reach*: Web GIS uses HTTP thus globally accessible. Users can access web GIS applications from their home computers or smartphones.
c. *Better cross-platform capability*: Web browsers, which are majorly used on the client-side, comply with HTML and JavaScript standards. This makes web GIS to be supported by almost all major operating systems.
d. *Low cost as averaged by the number of users*: The pricing strategy in many Web GIS facilities is either free or provision cost recovery (very low). Thus, enable the users to reduce the cost of purchasing and maintenance that is inevitable in traditional desktop GIS.
e. *Easy to use for end users*: It is commonly designed for simplicity, intuition, and convenience, making it typically much easier for the end users than desktop GIS which was intended for professional users.

The power utility aims at enhancing the efficiency of the transmission and distribution network in both technical and non-technical aspects. Technical improvements include re-conducting of lines, installation of capacitors, and construction of additional feeders and substations. Non-technical improvements include introduction of electronic meters, improvement of meter reading accuracy, fraud control and resolution of billing anomalies. Major power losses occur at the distribution level and this makes it the key focus area in power sector reforms. GIS can help reduce losses and improve efficiency through its contribution in the following areas of distribution reforms [11]:

i. *100% consumer metering and Accurate Meter Reading*: This entails installation of meters at all the transformation stages and in the consumer premises.
ii. *Feeder and Distribution Transformer (DT) metering:* Installation of static (electronic) meters on all 11 kV outgoing feeders and Distribution Transformers.

iii. *Effective Management Information System*: Both feeder and DT static meters record active energy, power factor and load information. This information is useful for quick decision making and improved distribution system.
iv. *Total energy accounting*: Energy received in each 11 kV substation and 11 kV outgoing feeders, energy billed and Transmission and Distribution (T&D) losses at each feeder and DT is properly accounted for.
v. *Installation of capacitor banks & network reconfiguration*: Installation of capacitor banks at all levels, reconfiguration of feeders and DTs in a way as to reduce the length of the Low Tension (LT) lines thereby reducing ATC losses.
vi. *High Voltage Distribution System (HVDS)*: Installation of small, energy-efficient DTs supplying power to 10 to 15 households only, re-conducting of overloaded sections, web mapping of the entire distribution system and load flow studies to strengthen the distribution system.

Web GIS can help in achieving the above reforms through the following applications:

a. *Creation of power network assets' database:* This data is then displayed on a web map using web GIS technology. Of particular importance is the sub-transmission and distribution network in which all the 33 and 11 kV substations, 11 kV feeders, DTs and LT feeders are mapped and geo-referenced.
b. *Creation of consumer database and consumer indexing*: Indexing of all the consumers in all categories so that, if necessary, the consumers can be segregated feeder-wise and DT-wise. The consumers are then mapped using GIS technology and identified based on their unique electrical address called Consumer Index Number (CIN).
c. *Load Flow Studies*: After mapping the power network assets' and consumers, the load and consumer profile can be studied and inferences drawn for rectifying imbalances in the network, load analysis in various network segments and load rearrangement.
d. *Load Forecasting*: GIS is an effective technology in optimal design and choice of substation location, demand-side management, future load assessment and load planning.
e. *Management Information System (MIS)*: Based on inputs from GIS, which is regularly updated and monitored, a robust MIS can be built for analyzing and reducing ATC losses, improved revenue billing and collection and load demand and supply analysis.

The increasing importance of GIS in the electrical power sector is evident in the study conducted by Hassan & Akhtar and presented in their paper entitled, "Mapping of Power Distribution Network using Geographical Information System (GIS)". In their summary of the findings, they report that "GIS mapping proved to be a very useful tool in decision making. No need of site surveys for preparation of new connections estimate." With the ever increasing need for access to information, GIS provides a solution by allowing easy and speedy retrieval of information. GIS also improves asset management, enhances preventive maintenance activities, and allows for effective planning of new works and line extensions.

This could form the basic and most fundamental application to which all other business processes in the power utility companies should be integrated [6].

### 2.4 Existing Electrical Network Web Maps

To obtain a full understanding of the broad capabilities that Geographic Information Systems bring to the electric power sector, it is necessary to recognize some existing applications in this sector. In this regard, the UK Power Networks' Distributed Generation Mapping Tool is considered.

The UK Power Networks is a distribution network operator for electricity covering South East England, the East of England and London. It manages three licensed distribution networks (Eastern Power Networks PLC, South Eastern Power Networks PLC and London Power Networks PLC) which together cover an area of 30,000 square kilometers and approximately 8 million customers. UK Power Networks maintains the electricity networks including the lines and electricity cables. In total there are 14 distribution network operators (DNOs) in the United Kingdom, each responsible for a different area of the country. These DNOs are all regulated by the Office of the Gas and Electricity Markets (Ofgem). According to the UK Power Networks' website, Distributed Generation (DG) refers to "a productive generator connection to an electricity distribution network. The most common generation sources are wind turbines, solar panels and combined heat and power (CHP)." The DG mapping tool shows the approximate locations of the 33kV and 132kV overhead electricity network poles. It also shows where the 11kV, 33kV and 132kV substations are located in the East of England and the South East. The 11kV substations become visible once the area where the network exists is zoomed three times [12].

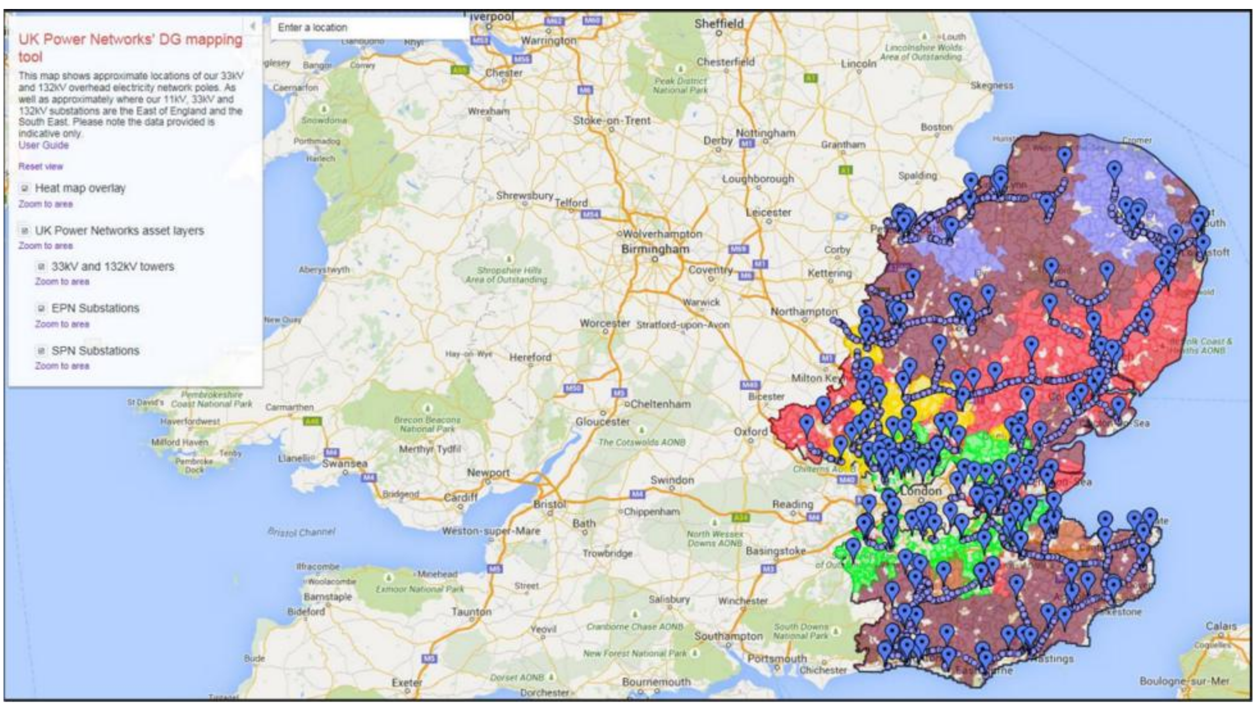


**Figure 3:** UK Power Networks' DG mapping tool

The map's search function enables the user to search for a place by simply entering either a place or postcode in the 'Enter a location' box. After a successful search the map will then reposition and centralize the chosen area. A user can view asset information by clicking on the asset icon from which an interactive popup containing the relevant asset information is produced.

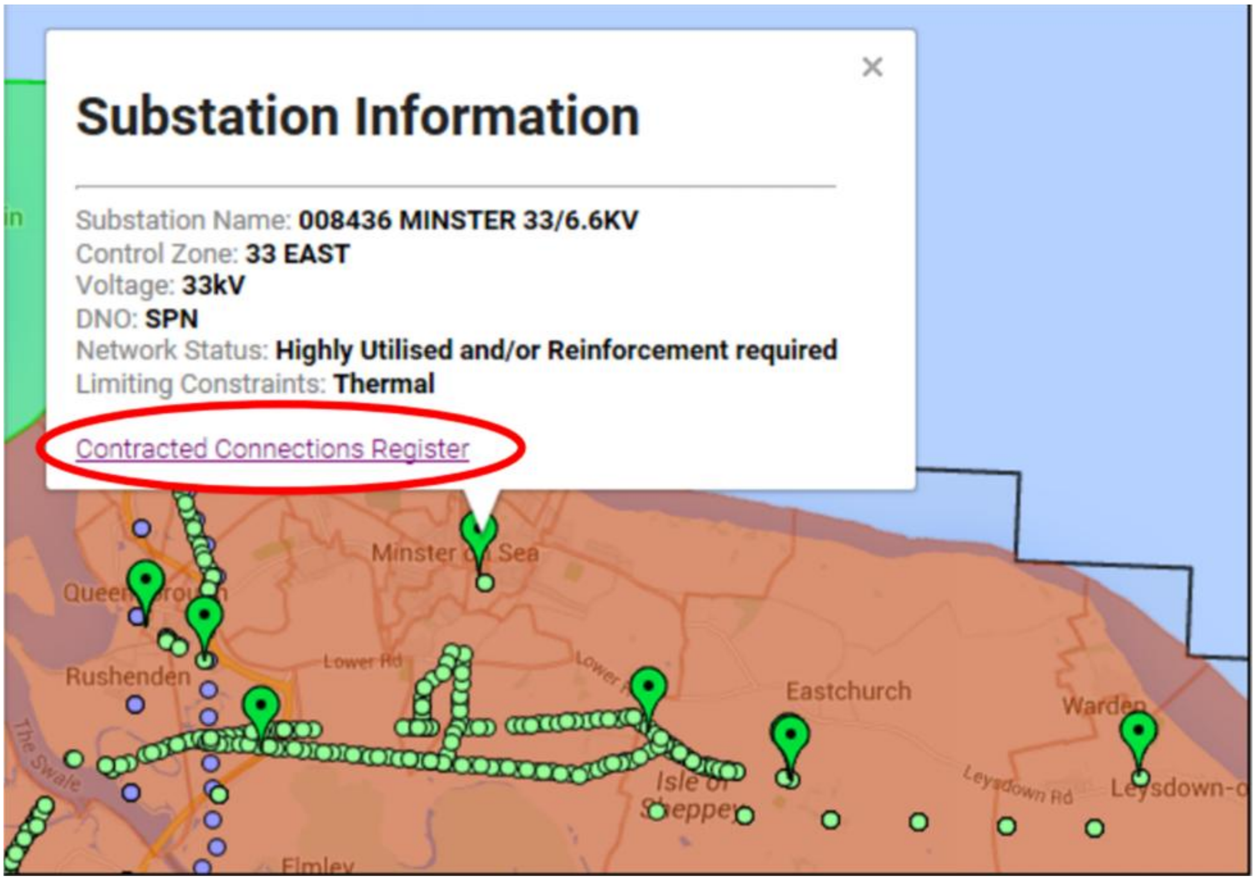


**Figure 4:** A popup displaying substation information

# Chapter 3: Methodology

The following sections describe the various steps of web map development as part of the potential and economical way to digitize the electrical power network and the business processes undertaken by electric power utilities in Kenya. It is developed by integrating PHP, Apache Web Server, HTML, JavaScript (specifically the Leaflet library), PostgreSQL and PostGIS by adopting a web-based client/server environment.

### 3.1 Area Selection

The first step in mapping was to specify an area to work on. Naivasha District was selected for this purpose. Its suitability is supported by the fact that all the three key business processes (generation, transmission and distribution) of the power sector are carried out. This project area can be extended further to the national level to achieve maximum benefits.

Administratively, Naivasha District was carved out of the larger Nakuru District in 2007. It is one of the districts within the Rift Valley Province. The district lies on the floor of the Great Rift Valley and borders Nakuru District to the North West; Kajiado and Lari to the East; Narok North to the South and Nyandarua South to the North. The District covers an area of 2837.4 square kilometers. It is divided into five administrative divisions namely Gilgil, Naivasha, Kongoni, Elementaita and Mai-Mahiu. The five divisions are further subdivided into 15 locations and 27 sub-locations. Geographically, Naivasha District lies between 0° 43’ 13’’ N and 36° 25’ 43’’ S.

### 3.2 Overview of Methodology

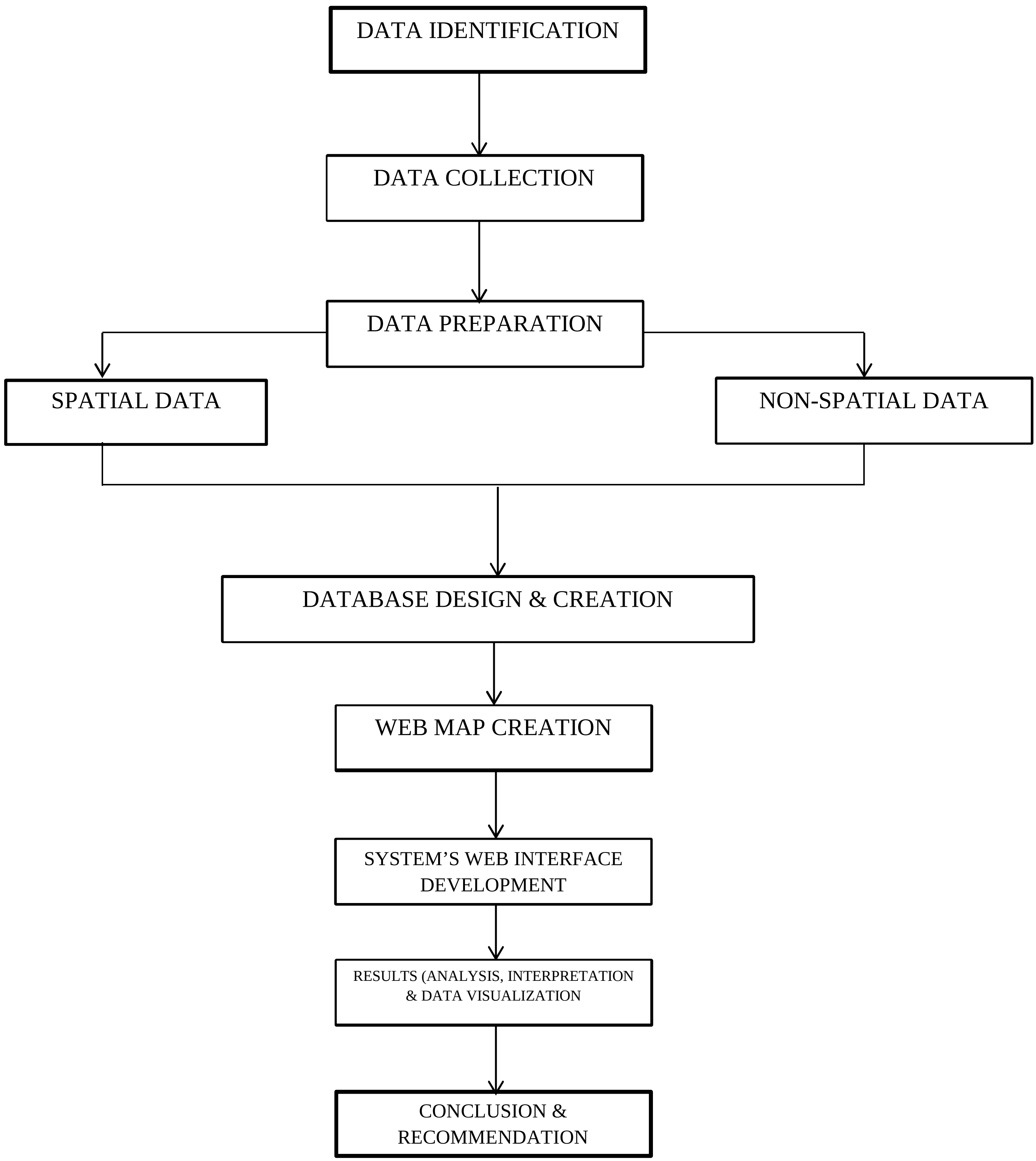


**Figure 5:** Overview of Methodology

### 3.3 Data Identification and Collection

This process involved the conceptual identification of data that was required for database design and creation followed by actual data collection. The electrical network assets considered were generators, power transformers, substations and transmission (and distribution) lines. The data used in the creation of the dynamic database include map data (spatial data depicting location of each asset) and attribute data (non-spatial data describing the physical and electrical characteristics of each asset).

Base map layers were obtained from MapQuest which provides base map layers in the form of map tiles, while map data was obtained from the free and open-source OpenStreetMap (http://www.openstreetmap.org ).

The network assets data was sourced from the key players in the electricity sector: KenGen, KPLC and KETRACO. The location and attribute data for substations and power transformers was obtained from KPLC's Survey Report (Central Rift Site Survey Report, 2014), Tender Specification Documents. Using Google Maps location functionality, the location of KETRACO's primary transmission substations was obtained. Generator location and attribute data was obtained from KenGen's Tender Documents and its website (http://www.kengen.co.ke ) with the help of Global Energy Observatory (http://www.globalenergyobservatory.org ).

### 3.4 Database Design

Designing a web site first requires the design of a relational database. Conceptually, this design involves two models: the *data model* and the *process model*. The data model focuses on *what* data should be stored in the database while the process model deals with *how* the data is processed. In the context of the relational database, the data model is used to design the relational tables while the process model is used to design the queries that will access and perform operations on those tables.

The database forms the foundation of all operations that will be performed using GIS such as map creation, data retrieval and spatial analysis modelling. The network assets database was designed to meet the feature functionality of the web interface and how the network would be graphically displayed on the map. The database design process was informed by the data at hand and the business processes being carried out by the possible end user (in the present case KPLC, KenGen, KETRACO, REA, and Ministry of Energy). This ensured that the resulting database meets user requirements, has effective data structures and efficient retrieval mechanisms, supports multi-user access and editing as well as is easy to update and maintain.

The database design process involved the three key steps listed below in the order in which they were performed:

i. Design of the database schema,
ii. Design of the programs that access and update the data, and
iii. Design of a security scheme to control access to data.

### 3.4.1 Relational Database Creation

The database was created in PostgreSQL with spatial functionality enabled using PostGIS. Four tables of the assets' attributes were created in this database: generator, transformer, substation and lines (includes transmission and distribution lines). The basic structures of the tables making up the database for the project are shown below.

**Table 1:** Generator Attributes

| ***No.*** | ***Name*** | ***Data Type & Length*** | ***Description*** |
|---|---|---|---|
| 1 | gen_id | VARCHAR(10) | Serial Number of generator |
| 2 | owner | VARCHAR (10) | Owner of the generator |
| 3 | gen_manfcr | VARCHAR (15) | Generator manufacturer |
| 4 | gen_manfc_yr | INT | Year of manufacture of generator |
| 5 | sync_mac_type | VARCHAR (20) | Synchronous machine type |
| 6 | mva_rating | INT | MVA rating of the generator |
| 7 | kv_rating | INT | Rated voltage of the generator |
| 8 | current | INT | Rated current of the generator |
| 9 | sync_speed | INT | Synchronous speed of generator-prime mover set |
| 10 | pfactor | REAL | Rated power factor |
| 11 | frequency | INT | Rated frequency |
| 12 | poles | INT | Number of generator poles |
| 13 | connection | VARCHAR(6) | Generator connection type |
| 14 | pm_id | VARCHAR(20) | Serial Number of prime mover |
| 15 | pmover_type | VARCHAR (30) | Type of prime mover |
| 16 | rated_head | INT | Prime mover's rated head in meters |
| 17 | max_head | INT | Prime mover's maximum head in meters |
| 18 | rated_output | REAL | Prime mover's output at the rated head |
| 19 | pmover_manfcr | VARCHAR (15) | Prime mover manufacturer |
| 20 | pmover_manfc_yr | INT | Year of manufacture of prime mover |
| 21 | install_yr | INT | Installation year of generator set |
| 22 | last_maint_date | DATE | Last maintenance date of generator set |
| 23 | lat | DECIMAL | Latitude of generator location point |
| 24 | lng | DECIMAL | Longitude of generator location point |
| 25 | area_name | VARCHAR (30) | Area name of generator location |

**Table 2:** Transformer Attributes

| *No.* | ***Name*** | ***Data Type & Length*** | ***Description*** |
|---|---|---|---|
| 1 | tx_id | VARCHAR(20) | Serial Number of transformer |
| 2 | owner | VARCHAR (10) | Name of owner of the transformer |
| 3 | kva_rating | INT | Capacity of transformer in kVA |
| 4 | prim_voltage | INT | Transformer's primary voltage |
| 5 | sec_voltage | INT | Transformer's secondary voltage |
| 6 | frequency | INT | Operating frequency of the transformer |
| 7 | mounting | VARCHAR(20) | Pole mounted, ground mounted, etc |
| 8 | prim_resistance | REAL | Resistance of transformer's primary winding |
| 9 | sec_resistance | REAL | Resistance of transformer's secondary winding |
| 10 | prim_reactance | REAL | Reactance of transformer's primary winding |
| 11 | sec_reactance | REAL | Reactance of transformer's secondary winding |
| 12 | per_unit_imped | REAL | Per Unit Impedance of the transformer |
| 13 | pfactor | REAL | Power factor of transformer |
| 14 | no_load_loss | REAL | Iron losses in the transformer windings |
| 15 | load_loss | REAL | Full-load copper losses in the transformer windings |
| 16 | phase | VARCHAR (5) | Shows whether the transformer is 1-ϕ or 3-ϕ |
| 17 | phase_not | VARCHAR(6) | Shows the phase notation, e.g., R-Y-B or R-B-Y |
| 18 | connection | VARCHAR(15) | Transformer connection, i.e., Y-Y, Δ-Δ, Y-Δ, Δ-Y |
| 19 | cooling | VARCHAR (6) | Cooling mechanism of the transformer |
| 20 | fuses | VARCHAR (8) | Shows condition of fuses: good, bad, OK |
| 21 | ht_jumper | VARCHAR (6) | Shows the HT jumper's condition as OK or loose |
| 22 | lt_jumper | VARCHAR (6) | Shows the LT jumper's condition as OK or loose |
| 23 | manfcr | VARCHAR (20) | Gives the name of the manufacturer |
| 24 | manfc_yr | INT | Gives the year of manufacture |
| 25 | install_yr | INT | Gives the year when the transformer was installed |
| 26 | last_maint_date | DATE | Gives the transformer's last date of maintenance |
| 27 | lat | DECIMAL | Gives latitude of the geo-location of transformer |
| 28 | lng | DECIMAL | Gives longitude of the geo-location of transformer |
| 29 | area_name | VARCHAR (40) | Gives the area/location name |
| 30 | location | VARCHAR (40) | Gives location name |

**Table 3:** Substation Attributes

| *No.* | *Name* | *Data Type &Length* | *Description* |
|---|---|---|---|
| 1 | ss_id | VARCHAR(10) | Substation number |
| 2 | ss_name | VARCHAR(20) | Name of substation |
| 3 | area_name | VARCHAR(20) | Area name of substation location |
| 4 | transformation | VARCHAR(20) | Voltage transformation of the substation |
| 5 | capacity | REAL | MVA rating of the substation |
| 6 | type | VARCHAR(20) | Type of substation |
| 7 | construction | VARCHAR(20) | Construction of substation |
| 8 | comm_date | DATE | Date of commissioning of substation |
| 9 | bus | VARCHAR(255) | Name and voltage of incoming buses |
| 10 | no_of_tx | INT | Total number of power transformers present |
| 11 | no_of_cb | INT | Total number of circuit breakers present |
| 12 | no_of_isolators | INT | Total number of isolators present |
| 13 | no_of_vt | INT | Total number of VTs present |
| 14 | no_of_ct | INT | Total number of CTs present |
| 15 | feeders | VARCHAR(255) | Feeder names and voltage |
| 16 | lat | DECIMAL | Latitude of substation location point |
| 17 | lng | DECIMAL | Longitude of substation location point |

**Table 4:** Line Attributes

| *No.* | *Name* | *Data Type* | *Description* |
|---|---|---|---|
| 1 | line_id | VARCHAR(10) | |
| 2 | conductor | VARCHAR(20) | e.g. 300mm$^2$ ACSR |
| 3 | code_name | VARCHAR(10) | |
| 4 | owner | VARCHAR (10) | |
| 5 | line_name | VARCHAR (15) | |
| 6 | kv_rating | INT | |
| 7 | capacity | INT | |
| 8 | thermal_current | INT | |
| 9 | thermal_mva | REAL | |
| 10 | resistance | REAL | |
| 11 | reactance | REAL | |
| 12 | inductance | REAL | |
| 13 | length | INT | |
| 14 | radius | REAL | |
| 15 | spacing | INT | |
| 16 | start_lat | DECIMAL | |
| 17 | start_lng | DECIMAL | |
| 18 | end_lat | DECIMAL | |
| 19 | end_lng | DECIMAL | |

### 3.5 Development of System's Web Interface and Creation of Web Map

This involved algorithm development and actual coding on an Integrated Development Environment using HTML, PHP and JavaScript. Before implementing the actual design of the project, a few user interface designs were constructed to visualize the user interaction with the system as they browse for power network assets' data and view the information on the map. Web pages for altering or updating the database are only accessed by users with administrative privileges.

### 3.6 Business Process Carried out in the System

The web-based network map supports the automation of various business operations of power utilities such as planning, engineering, operations and accounting applications.


**Figure 6:** GIS applications in the power sector

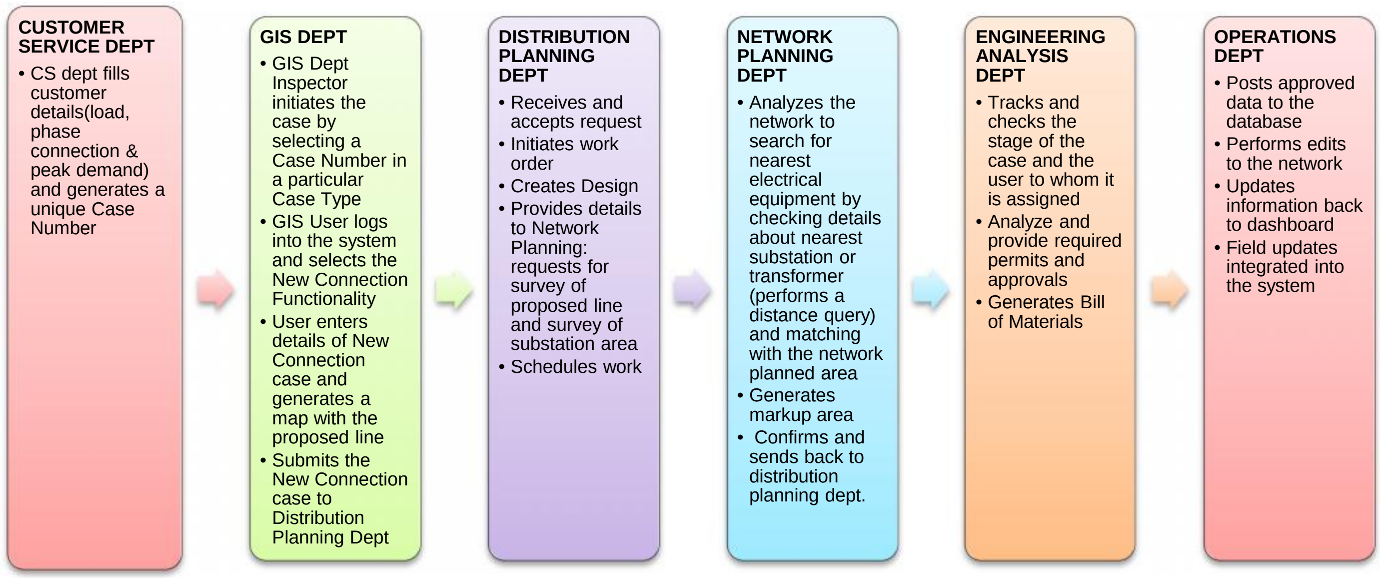


**Figure 7:** New Customer Connection Case

A new customer connection case was considered under Customer Service; this process involves the input of various departments of the utility at different stages of its implementation as can be seen in the workflow management process in Figure 7 above.
After finalizing payments with KPLC the customer waits for power connection. The network operators at KPLC's Network Planning Department must ensure that the customer's service line is tapped from the most optimal transformer. Presently, the conditions for power connection are that: the customer must be within a radius of 600m from an existing transformer (with a tolerance of ±100m following the way-leaves), and the total connected load on the transformer should not exceed 80 percent of its capacity.

Figure 8 below shows the flowchart for a new connection case for a domestic consumer at the distribution transformer (11/0.415kV) level. In a situation where this connection requires the installation of a new distribution transformer, the result is a new or additional load on the nearest substation. Thus, Figure 9 shows the flowchart for a new or additional load connection at distribution substation level.

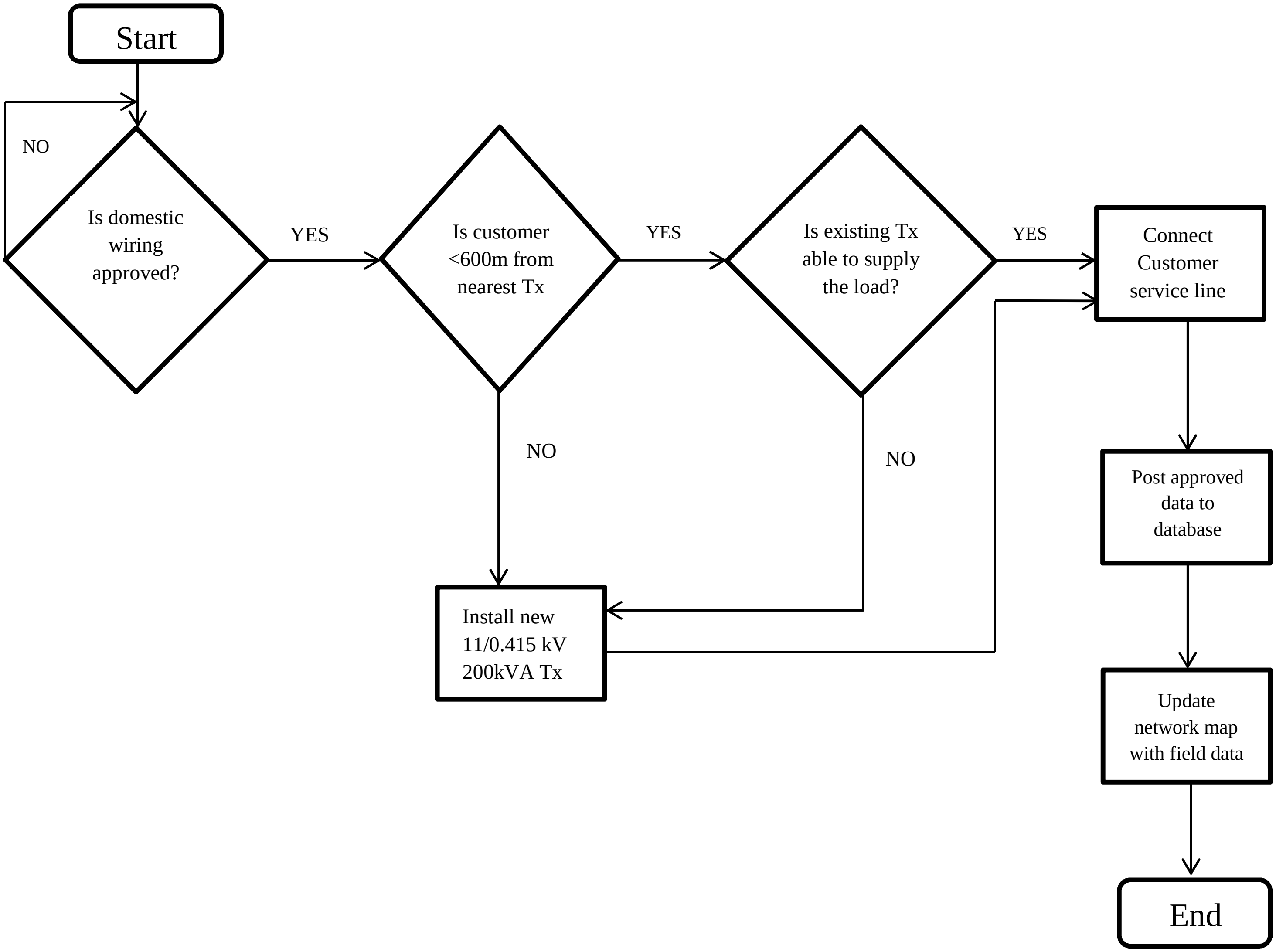


**Figure 8:** New Customer Connection

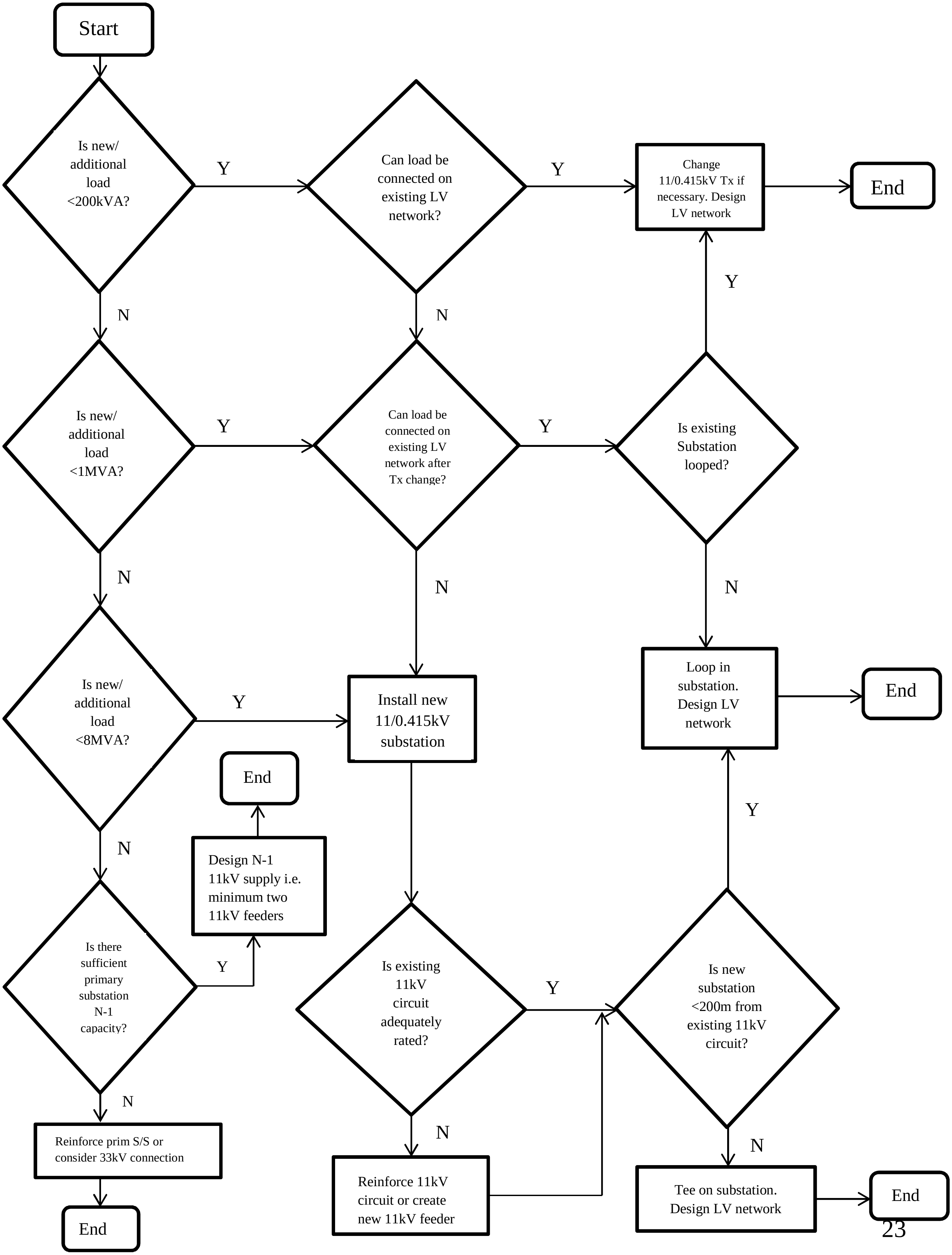


**Figure 9:** New or Additional Load Connection

# Chapter 4: Results and Discussion

## 4.1 Results

The final result of the system development effort under this study was an interactive web based GIS system consisting of a dynamic database and a web based user interface made up of six web pages (Home, Generation, Transmission, Distribution, Network Assets and PowerGrid Map) running on the user's web browser.

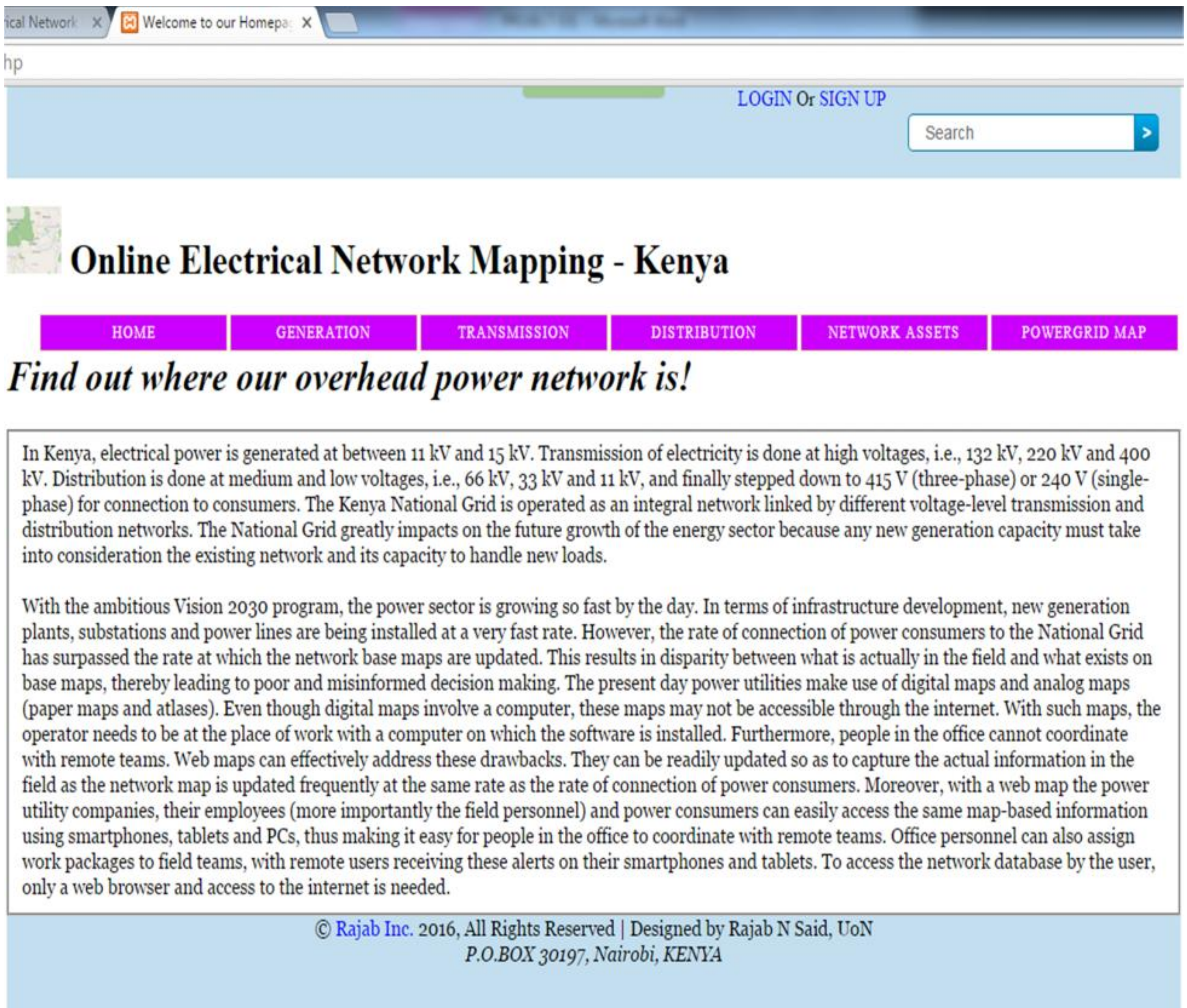


**Figure 10:** Home page

### i. Web Map

The resulting web map is shown in Fig.11 below. It shows the geographic locations of power transformers, substations, generators and power lines (transmission and distribution lines) with their attributes. The assets' attributes can be viewed by clicking on the asset's icon upon which a popup is displayed with the respective asset information. The web map has among others the following functionalities:

*Visualization*: The web interface allows easy and convenient access to the electric network assets on an interactive web map.

*Search*: A user can search for network assets from the database and the result displayed on a map. For instance, one may perform a distance query such as the nearest transformer in a given location or the location of all 132-kV transmission lines within 100 kilometers of a given site. The system produces both a map and a list of those transmission lines.

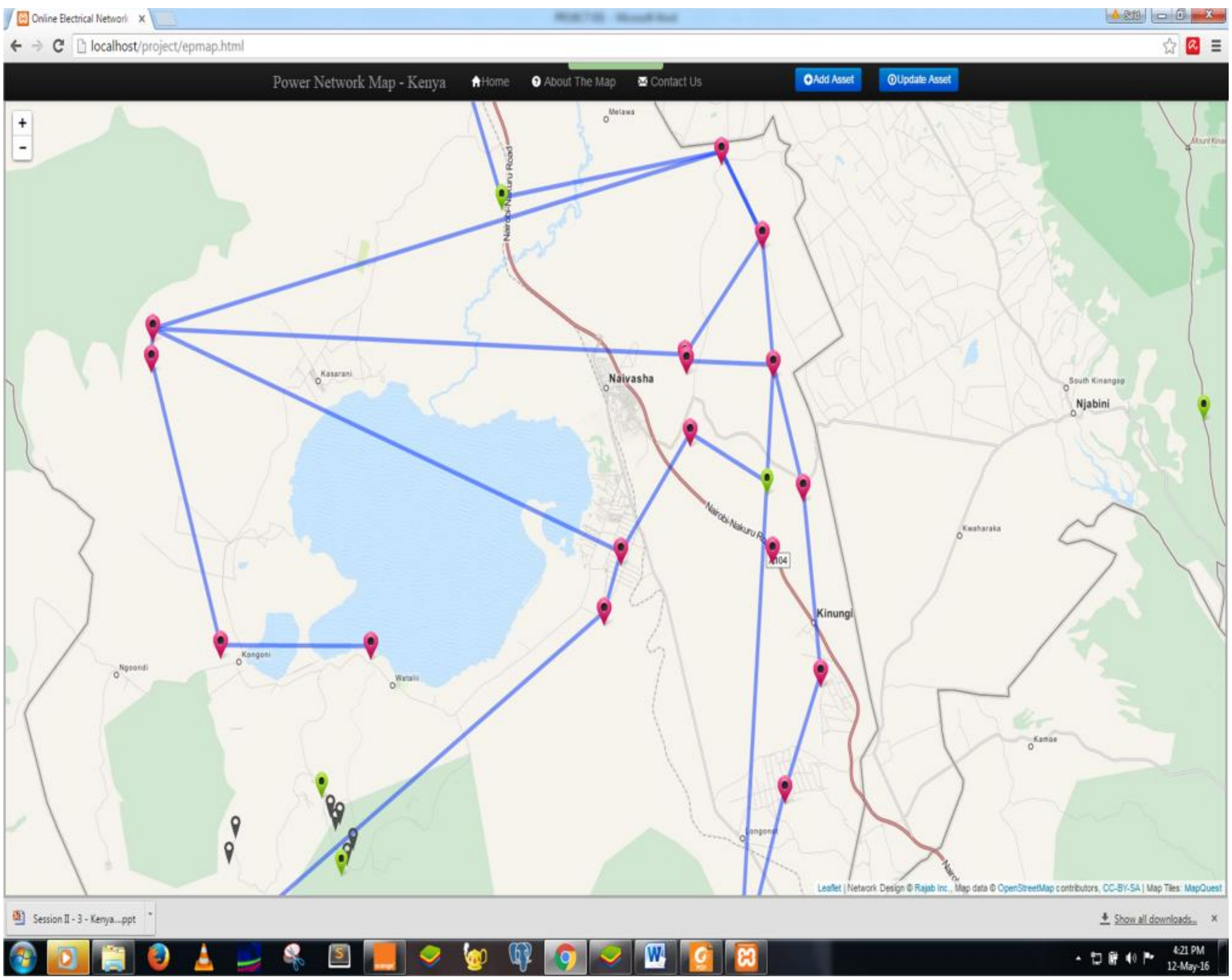


**Figure 11:** Web map

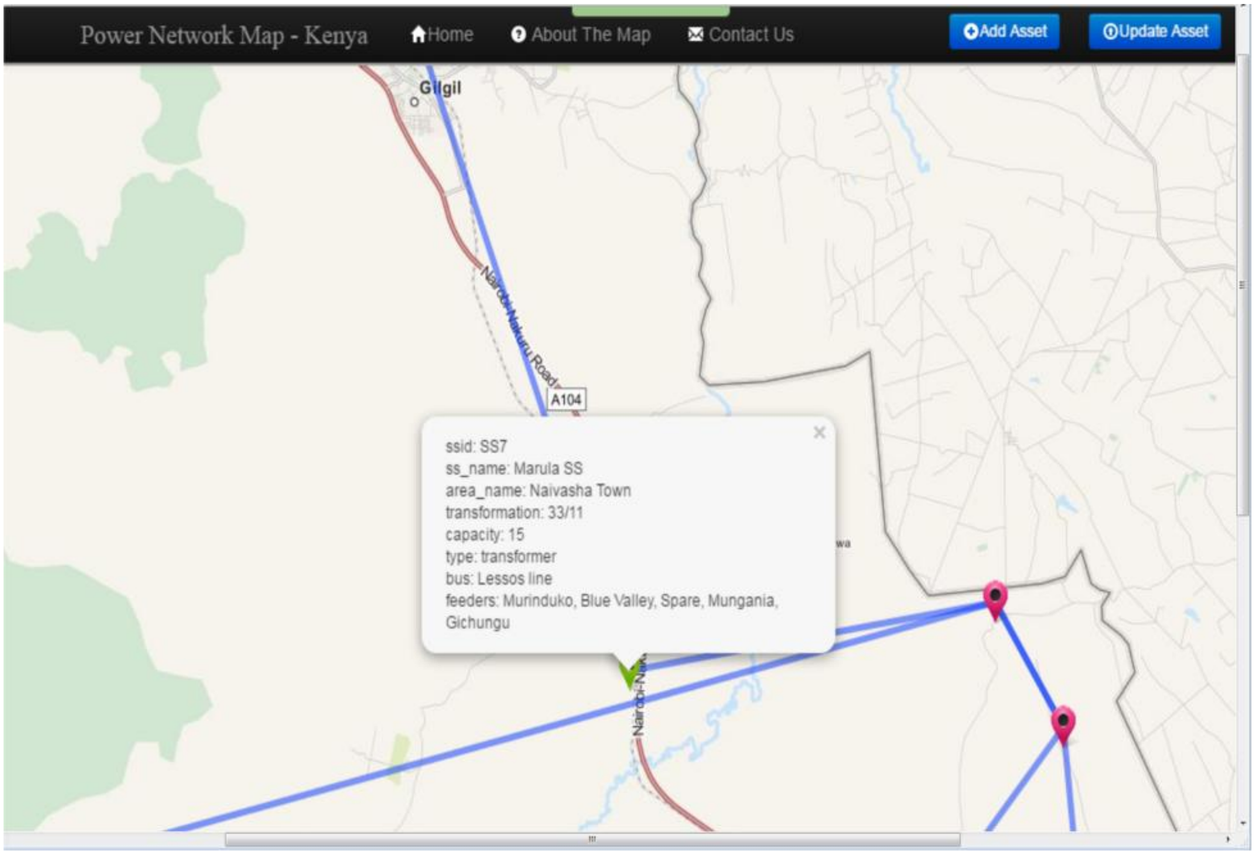


**Figure 12:** Popup showing substation information

### ii. Sample SQL query

The SQL query below was run against the database to give all three-phase transformers with a star-delta connection. The results display the kVA rating, the primary and secondary voltage, the serial number as well as the geographic location (longitude and latitude) of the transformers as shown in Fig. 13 below.

```sql
SELECT  kva_rating  as  rating,
            prim_voltage  as  hv,
            sec_voltage  as  lv,
            ST_AsText ( transformer.geom )  as  geometry,
            serial_no  as  sno
FROM
            transformer
WHERE
            connection  =  'star-delta'  AND
           phase  =  '3-Φ'
ORDER BY
            kva_rating  DESC;
```

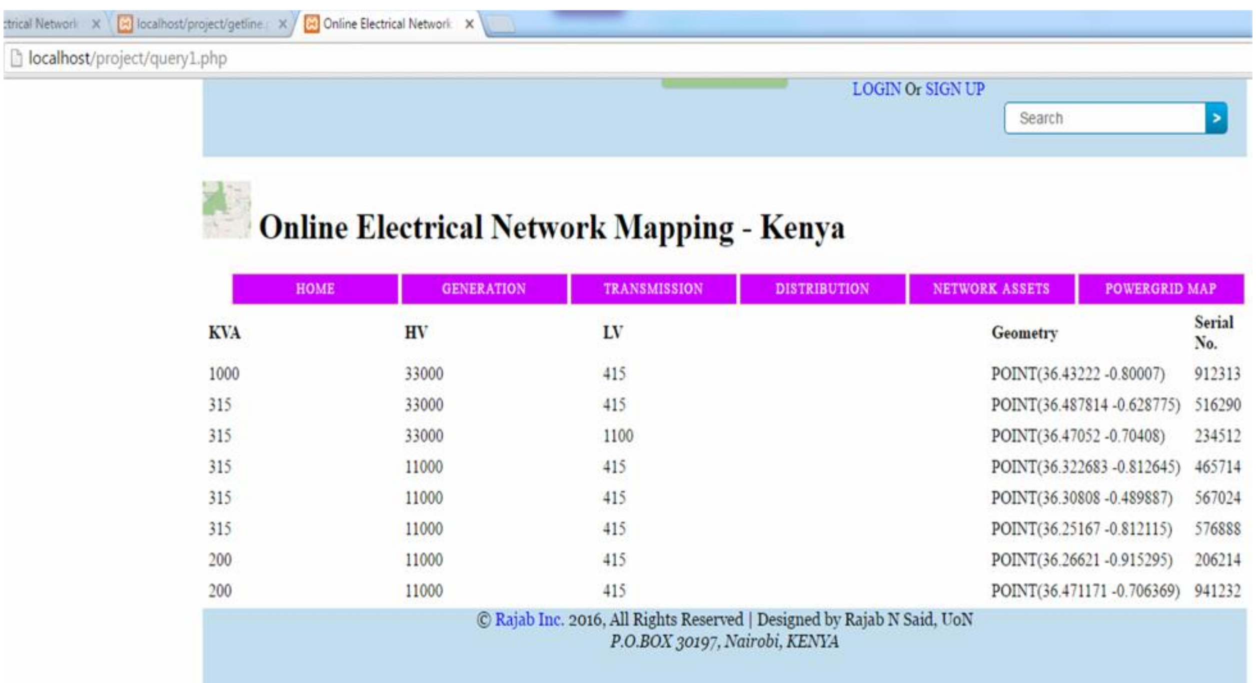


**Figure 13:** 3-Φ star-delta connected transformers

### 4.2 Discussion

The results reveal that the system web interface provides a revolutionary approach in the electricity sub-sector's activities. Different users can now readily access important information about the electricity network irrespective of where they are at any point in time. The dynamic database and the web map lead to more efficient network maintenance and more effective emergency response. The whole system helps power utilities to effectively track and manage distribution networks with asset and location data in a usable format. Some of the very important activities being carried out by power utilities can be performed efficiently using the system developed, for instance:

***Asset Inventories***: Create and maintain an inventory of asset location and attribute information in a relational database management system.
***Asset Maintenance***: Update asset location and condition and schedule repair and maintenance. For example, if there is an outage on the transmission system and the location of the problem is known, a dispatcher can reference it on the web map and give maintenance crews exact information about how to get to the trouble spot for repairs.
***Inspections***: Maintain digital records and location of field assets for the utility's asset assessment.

The results show that, using GIS, power utilities can intelligently plan, build, monitor, and manage their transmission and distribution networks. The system offers generation and transmission companies a method of quickly accessing and producing maps, leveraging database information, and automating business processes. It is an important tool that can be used to help site transmission lines and facilities, to identify asset features, and to conduct studies that require analysis of the geographic distribution of data. The ability to access both spatial and non-spatial data of the electrical power network on a web based platform underscores the importance of incorporating a geographical context in the network assets data.

# Chapter 5: Conclusions & Recommendations

## 5.1 Conclusion

The objective of the project was to create a web interface that allows a user to build a dynamic database of power network assets from which the generation, transmission and distribution of electric power can be mapped. Essentially, this objective has been achieved and the following conclusions are made:

a. Data on electrical network assets is now available on an interactive web interface system where power utility employees can visualize spatial information about the network assets on a web map and access their attributes through popups. The web map can be readily updated so as to capture the actual information in the field.
b. Useful information is now available to office personnel and field personnel for effective performance. With the web map the power utility employees (more importantly the field personnel) and power consumers can easily access the same map-based information using smartphones, tablets and PCs, thus making it easy for people in the office to coordinate with remote teams.
c. Power utility office personnel can assign work packages to field teams, with remote users receiving these alerts on their smartphones and tablets. This ensures fast emergency response.
d. With the ability to perform database queries the user is able to filter the data so as to remain with relevant data, which can then be viewed in a tabular format or on the web map.
e. The power utility can create and maintain an up-to-date inventory of asset location and attribute information in a usable format to effectively track and manage distribution networks.
f. Maintaining a power network assets' database combined with 100% consumer metering and accurate meter reading helps power utilities in reducing system losses (technical and non-technical) and improving efficiency

## 5.2 Recommendations

In order for initiatives such as KPLC's aim to enhance the power system operational efficiency and improve customer satisfaction to be a success, there is need to include the use of technology that incorporates a geographic context in the power system network. In this regard, the following recommendations are made:

a. Integrate GIS technology with power network operations to build an interactive real-time power network which improves reliability and performance.
b. Train some of the electrical engineers in the power utility on the use of web GIS, since it has been very useful and has several applications.
c. Invest in modern technology like the web and GIS to ensure efficient, reliable and effective power transmission and distribution.

## REFERENCES


1. Kenya. Energy Regulatory Commission. *Kenya Electricity Grid Code*. Nairobi: 2008.
2. Kenya Power and Lighting Company Limited. *Annual Report and Financial Statements 2014/2015*. Nairobi: Kenya Power and Lighting Company Limited, 2015
3. Pickering, David F., Jonathan M. Park and David H. Bannister. "Utility Mapping and Record Keeping for Infrastructure". Washington, D.C.: The World Bank, International Bank for Reconstruction and Development, 1993.
4. Buckley Aileen. "Designing Great Web Maps". Esri Mapping Center Lead. 2012.
5. Otto Huisman and Rolf A. de By, (eds). Principles of Geographic Information Systems, $4^{th}$ ed. Enschede: ITC, 2009.
6. Hassa, H.T. & Akhtar M. Faheem. "Mapping of Power Distribution Network using Geographical Information System (GIS)." *International Journal of Emerging Technology and Advanced Engineering* 2.6 (2012): 343 – 347.
7. Dangermond, J. "Enterprise GIS: Powering the Utility of the Future." GITA. 2008.
8. Singh Puyam S., Dibyajyoti Chutia and Singuluri Sudhakar. "Development of a Web Based GIS Application for Spatial Natural Resources Information System Using Effective Open Source Software and Standards". *Journal of Geographic Information System* 4.3 (2012). Accessed 03 Dec 2015. <www.scirp.org/journal/PaperInformation.aspx?PaperID=19600>
9. Singh, Sunil P. and Preetvanti Singh. "Mapping Spatial Data on the Web Using Free and Open-Source Tools: A Prototype Implementation". *Journal of Geographic Information System* 6.1 (2014). Accessed 03 Dec 2015. <www.scirp.org/journal/PaperInformation.aspx?PaperID=42825>
10. Fu, P. and Sun, J. Web GIS: Principles and Applications. New York, USA: ESRI Press, 2011.
11. Raghav, S.P.S and Jayant K Sinha. "Electrical Network Mapping and Consumer Indexing using GIS". Dehradun, UPCL.
12. UK Power Networks (Operations) Limited. Distributed Generation Mapping Tool User Guide. London, UK. Accessed 03 Dec 2015. <http://www.ukpowernetworks.co.uk/internet/en/our-services/connections-work-outside/electricity-generation/find-outwhere-our-overhead-network-is >