Spatial Informatics and Geographical Information Systems: Tools to Transform Electric Power and Energy Systems

by

A. Nagaraja Sekhar, K.S.Rajan, Amit Jain

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Centre for Power Systems
International Institute of Information Technology
Hyderabad - 500 032, INDIA
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Spatial Informatics and Geographical Information Systems: Tools to Transform Electric Power and Energy Systems

A. Nagaraja Sekhar, K. S. Rajan, and Amit Jain, Member *IEEE*

Abstract—**Electric Power and Energy Systems are the key for the growth of any developing country. Electric power shortage is one of the main culprits that hinder the spread of development across these countries and cause of societal disparity. Innovative Spatial Informatics and Geographical Information System Techniques have come as the boon to solve many problems in the Electric power system where demographical and geographical spread was the root cause of problem. This paper aims to give a general view of Spatial Informatics and geographical information techniques and their possible use in specific Electric power and Energy problems in changing business environment, where the customer satisfaction has a direct bearing on the profitability of a utility. The GIS medium integrates both landbase and the electrical network maps. The GIS overlays single line diagrams of the power network with updated customer, meter, and network for system planning, data analysis and reporting. Energy audit, asset management, network analysis, customer management can be accomplished by GIS functionality. GIS also provides seamless environment for applications like transient stability, long term load forecasting, load flow and short circuit analysis.**

Index Terms: **Distribution Systems, Electric Power Systems, Geographical Information Systems (GIS), Global Positioning System (GPS), Spatial Informatics, Spatial Energy Management System (SEMS)**

I. INTRODUCTION

A Geographic Information System (GIS) is an automated information system that is able to compile, store, retrieve, analyze and display mapped data [1]. GIS system combines various layers [fig.1] of information about a place for better understanding and depending on the purpose, different layers can be put together for better analysis. The requirements of the different layers include, finding the best location for a new store, analyzing environmental damage, viewing similar crimes in a city to detect a pattern, keeping an overview of the electrical grid and so on. The power of a GIS over paper maps is its ability to select the information needed depending up on the intended application.

The features of GIS are being introduced into power distribution systems for developing better working models of various aspects like:

- Fault Location determination based on Geo-referencing.
- Topology Analysis & Fault Isolation
- Requirement Analysis
- Resource Allocation --- Tools, Manpower
- Generate Work Order
- System Restoration

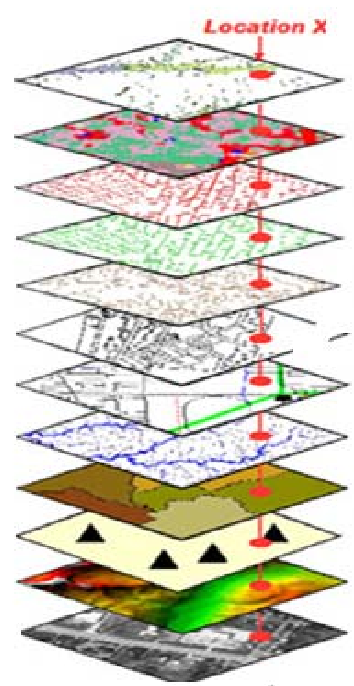

Fig.1. Layers in GIS

The literature reveals that, a well-designed GIS based transmission and distribution network may help minimize loss of electricity and enable pooling of supply and demand in order to maximize efficiency of the electric power system and reduce environmental impacts of power generation.

Map data used by GIS are collected from existing maps, aerial photos, satellites, and other sources. A digitizer or

A. Nagaraja Sekhar is a part time research student in the International Institute of Information technology and a full time faculty at Chaitanya Bharathi Institute of Technology, Hyderabad. (email: nagaraj_09@yahoo.com)

K. S. Rajan is an Associate Professor at the International Institute of Information Technology, Gachibowli, Hyderabad. (email: rajan@iiit.ac.in)

Amit Jain is an Assistant Professor at the International Institute of Information Technology, Gachibowli, Hyderabad. (email: amit@iiit.ac.in)

similar device is used to convert compiled map data to a digital form in order to make it computer compatible. This transformation allows the storage, retrieval, and analysis of the mapped data to be performed by the computer. Maps produced by a GIS are typically displayed on computer monitors or are printed on paper. The power of GIS lies in its ability to analyze the data and to present the results of that analysis as more meaningful information than any other traditional systems.

The GIS database contains both map data (spatial data depicting location of geographical objects) and attribute data (non-spatial data describing physical characteristics of each object) fig.2(a) and fig. 2(b). During a GIS analysis, site (map) data is linked with situation (attribute) data for each object mapped. It is this link, which is automatically performed by the GIS software that gives GIS its analytical power. Another advantage of GIS is its interface with GPS, which eliminates the need to send a surveying crew to locate utility facilities and then transfer field notes onto the maps.

Fig 2a: Spatial data

State ID	Name	Population	Area	Population density
1	Jammu Kashmir	10,069,917	222236	453118
2	Himachal Pradesh	6077248	55673	109.16
3	Punjab	24289296	50362	482294
4	Haryana	21082989	44212	476.861
5	Uttaranchal	8479562	53484	158.544

Fig 2b: Non-Spatial data

II. Global Positioning System

The Global Positioning System (GPS) [2], [3] is one of the main building blocks, helping in creation of any GIS system. It is a location system based on a constellation of about 24 satellites orbiting the earth at altitudes of approximately 11,000 miles. GPS satellites are orbited high enough to avoid the problems associated with land based systems, yet can provide accurate positioning 24 hours a day, anywhere in the world. The GPS is made up of three parts: satellites orbiting the Earth; control and monitoring stations on Earth; and the GPS receivers owned by users. GPS satellites broadcast signals from space that are picked up and identified by GPS receivers. Each GPS receiver then provides three-dimensional location (latitude, longitude, and altitude) plus the time. GPS can provide any point on earth with a unique address (its precise location). A GIS is basically a descriptive database of the earth (or a specific part of the earth). GPS tells you that you are at point X,Y,Z while GIS tells you that X,Y,Z is an oak tree, or a spot in a stream with a pH level of 5.4. GPS tells us the "where". GIS tells us the "what". The "what" is the object or objects which will be mapped. These objects are referred to as "Features", and are used to build a GIS. It is the power of GPS to precisely locate these Features which adds so much to the utility of the GIS system. On the other hand, without Feature data, a coordinate location is of little value.

A. *GPS Applications*

One of the most significant and unique features of the Global Positioning Systems is the fact that the positioning signal is available to users in any position worldwide at any time. With a fully operational GPS system, it can be generated to a large community of likely to grow as there are multiple applications, ranging from surveying, mapping, and navigation to GIS data capture.

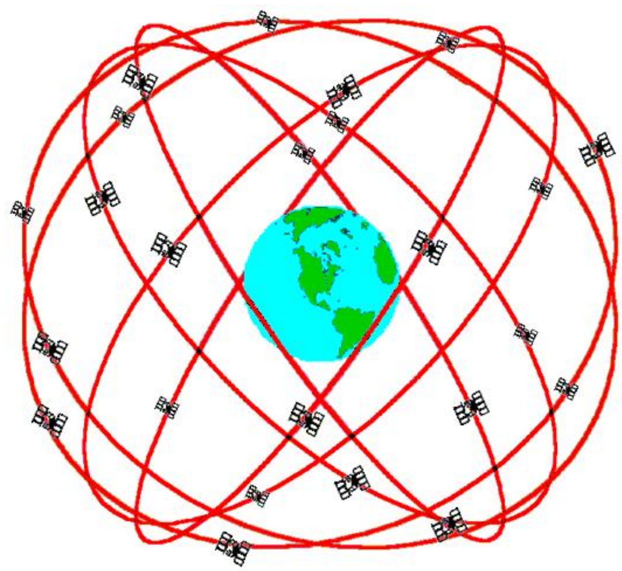

Fig. 3a. GPS Nominal constellations of 24 Satellites in 6 orbital planes, 4 satellites in each place, 20, 200 Km Altitudes, 55 degree inclination.

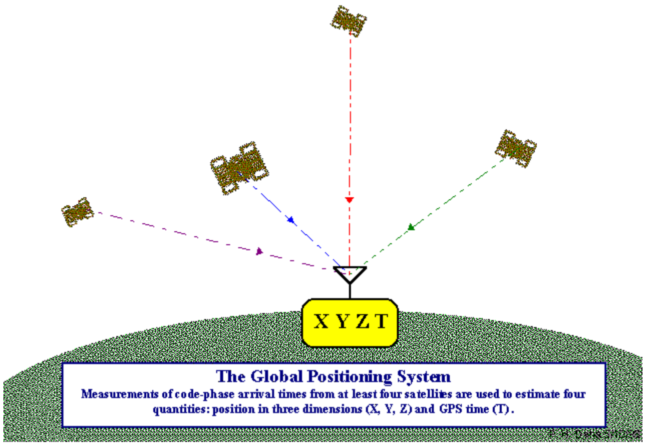

Fig. 3b. Measurement of co-ordinates in three dimensions

Fig. 3c. GPS Receivers

GPS receivers come in a variety of formats [3], from devices integrated into cars, phones, and watches, to dedicated devices

The accuracy of currently available GPS devices varies from around 20m to sub-meter levels, depending on the configuration of these systems. With the addition of GLOSNAS, GALILEO, GAGAN (Indian Navigational Satellite Systems) and other GNSS in the coming years, a high level of accuracy for utility mapping is expected to be achieved.

III. Spatial Questions That Drive an Analysis

Spatial questions allow a critical examination of a problem laying the foundation of requirement and development of GIS applications. The following questions are commonly asked:

- What exists at a particular location (locational analysis)?
- When is a specific spatial condition satisfied?
- What has spatially changed over time?
- What kind of pattern will emerge from geographical data?
- What will happen if certain phenomena are entered into predetermined scenarios?

When attempting to answer a geographic question, the user determines which phenomena are to be examined and how the analysis will proceed. A GIS provides a set of "tools" or computer programs that allow the user to perform a specific set of operations on map and attribute data. These tools, which are in the form of operating commands, permit spatial inquiry, manipulation, and analysis (spatial and network analysis).

One of a very powerful spatial concept is called buffering, which is a process used to determine the proximity relationship between features. Given any set of objects, which may include points, lines or areas, a buffer operation builds a new object or objects by identifying all areas that are within a certain specified distance of the original objects. In GIS, the units of buffering are points, lines and polygons. Buffer operations refer to the creation of a zone of specified distance around coverage features.

Spatial data usually consists of different types of objects. Object types include points, lines and polygons. Buffering point data is the simplest form of buffering which involves creation of a circular polygon about each point of radius equal to the buffer distance. The buffer distance or the radius of the circle could be fixed for all points in a layer or the user could specify it. If multiple points in the same layer are being buffered, then the buffering algorithms check for overlays, in points buffer and remove the overlapping sections.

IV. Spatial Informatics and GIS Applications for Electric Power and Energy Systems

A GIS allows the operator to: (1) incorporate (import) data from outside sources, (2) easily update and alter data, and (3) ask data-related questions on (or query) the database. The database management system (DBMS) software that is a part of a typical GIS provides these capabilities.

Geographical Information Systems (GIS) based systems in engineering applications has advantages which improves the performance, since GIS takes the inputs of the spatial and non-spatial data, monitors and analyzes with higher reliability in space and time dimensions. The GIS medium integrates both landbase and the electrical network maps. The GIS overlays single line diagrams of the distribution network with updated customer, meter, and network for distribution planning, data analysis and reporting.

The Transmission and Distribution losses in India are in the range of 40-45%. These can be reduced by using Spatial data and GIS and improve energy efficiency in the following areas [4]:

- 100% consumer metering and accurate meter reading i.e. installation of meters at all the transformation stages and in the consumer's premises.
- Feeder and Distribution Transformer metering: Installation of electronic meters on all out going feeders and DT's.

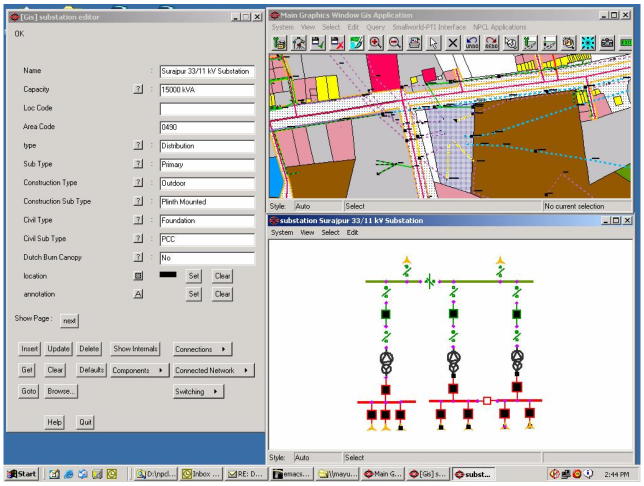

Fig. 4. A typical GIS application snapshot for Electric Network

- The feeder and DT meters record active energy, power factor and load information. The information can be downloaded to a computer network to build effective MIS for quick decision making and improved distribution system.
- Energy received in each substation and outgoing feeders, energy billed and T&D losses at each feeder and DT can be properly accounted for total energy.

GIS can be put to operation, in the above mentioned areas, for the creation of consumer database and consumer indexing. The consumers can be mapped using GIS techniques for recording spatial and non-spatial data and can be identified with a unique address called consumer index number.

Similarly, the distribution network with all its substations, feeders, DT and LT feeders can be mapped and geo-referenced with unique identification, thereby creating a database. All the existing connections and consumer details can be graphically displayed on the GIS map linked to the database.

For every substation the elements that were imported in the database and can be viewed on the map are:

1. Name of the substation
2. Number of busses
3. Type of the substation
4. Transformer data
5. Capacitor banks
6. Load Demand data

Similarly, the elements for the transmission lines [5] include:

1. Circuit type
2. Circuit length
3. Electrical data such as Resistance, Reactance, and Succeptance
4. Additional information like material properties, etc.

V. Transmission Line Routing using GIS

GIS application for the transmission Line Routing problem, where we are giving more insight into the electric problem, explain in a better way how GIS use can help in resolving the unseen problems, which is not easy to solve unless we integrate spatial concept with traditional/conventional/available routing solutions.

The transmission line routing is highly complex, as transmission lines are not aesthetically pleasing, and people are concerned about health issues due to the electric and magnetic fields, especially from high voltage transmission lines. GIS is used in transmission line routing as a technical tool.

During the route selection for a transmission line, a straight route with minimum curves is desirable as it gives the best engineering and economic solution – often based on Euclidean distances. In order to achieve this route the line may have to pass through certain places which are already inhabited by people or areas that are unsuitable for locating the transmission towers. Depending upon the population density and other factors, either the community is relocated or the route of the transmission line needs to be changed.

GIS can be used to analyse the selection of suitable areas for transmission lines, so that there is minimal environmental disruption such as minimizing the number of trees that are cut down when transmission lines are to be positioned across a forest area, implement optimal routing algorithms based on electrical and material properties in addition to locational characteristics, visualize the network on a map and help make appropriate decisions apriori and reduce cost escalations (due to re-routing, etc) during the implementation phase.

Electromagnetic fields (EMF) occur independently of one another as electric and magnetic fields at the 60-Hz frequency used in transmission lines, and both are created by electric charges. Electric fields exist when these charges are not moving. Magnetic fields are created when the electric charges are moving. The magnitude of both electric and magnetic fields fall off rapidly as the distance from the source increases (proportional to the inverse of the square of distance). Typical 230 kV transmission power lines produce average fields at distances of 30 and 60 meters as follows:

Line Voltage	Electric Fields (at 30/60 meters)	Magnetic fields (at 30/60 meters)
230 kV	0.3 / 0.05 milligauss	7.1/1.8 milligauss

To estimate the maximum fields, calculations will be performed at mid-span where the conductor is positioned at its lowest point between structures (the estimated maximum sag point). The magnetic fields are computed at 1 meter above ground.

Buffer zone concept from spatial informatics can help in routing the High tension transmission line near to a populated area, where spatial buffer zone will protect the inhabitants from strong electric and magnetic field effects.

Another example of utilization of buffer zone concept can be visualized in the transformer installation plan during an electrical network expansion. If an engineer needs to know the date of installation of a transformer all that he needs to do is click on the transformer symbol on the map and a table will appear detailing all the information on that particular transformer. If he wants to know how many transformers are installed in a given locality, the GIS will process the network data within the buffer zone of the desired locality and provides the results.

VI. Other Potential Applications

There are various other tools and techniques in a GIS system that can be used in effectively managing, monitoring and improving the performance of an Electric Power and Energy System. Optimization of resources will need an understanding of both the electrical properties and other socio-economic information for better delivery of services, leading to the need to collate, understand and analyze a large variety of spatial and non-spatial data. In rapidly growing cities there is a continuous challenge to provide for more and more power for both commercial high net worth customers and the new residential areas that get built up. In such cases, a reworking of the distribution network or addition of new distribution networks/elements is a constant need. In addition to the techniques discussed in the above two sections, spatio-analytical approaches of GIS can help identify and locate these new expansions/additions. Given the link of GIS with the database systems, a temporal change analysis can also be done for keeping track of the need for maintenance, system upgrades, and improvements carried out in a given network to meet the objectives and aspirations of the customers. For example, the Cyberabad region of the Hyderabad metropolitan area has seen a rapid growth in the last decade and is expected to grow more rapidly in the next few years – a recent study done at IIIT-H for the state government [6] indicates an additional 300,000 working population within the next few years (2007-2012) and more than doubling of the residential flats/houses (to around 115000) from the current 52, 000.

Modeling and simulation of the electrical networks is another possibility if the entire network information is available in a spatially referenced system. GIS based power system models can be developed and deployed to understand the impact of climatic and other factors that can alter/influence the transmission networks. Also, load balancing, discretionary switching of the load, load shedding, and load forecasting can be implemented in such a system taking into account the spatial distribution of the types of customers, their respective needs at varying hours of the day, and other parameters that influence such decision making, thus improving the decisions making ability at various levels of the network management.

There are some examples of the adoption of GIS techniques and its implementation in India and abroad [5],[7], which are at a nascent stage, mostly focusing on customer level analysis for detecting pilferages, power leakages, tampering with meters, etc. These applications have mainly been also used in building up inventory systems of electric poles, transformers, substations, etc., and for management of the troubleshooting and maintenance.

VII. Conclusion

The capability of GIS for displaying and analyzing information from diverse sources provides for a powerful interface for multifaceted understanding of the problems/issues, thus providing a framework for development of suitable and appropriate solutions. In case of power systems, GIS enhances its visualization by associating spatial data with transmission and other assets. To take proper decisions, information must be collected and analyzed to its full extent. Information on the facilities, their condition and their connectivity is important in taking control decisions. With the use of GIS, power companies can collect and store a large amount of data that can be readily accessed and analyzed. Hence, GIS and its applications play an important role in modern power system planning, analysis and control.

In essence, it will help improve the capability of an Energy Management Systems (EMS) to incorporate the spatial characteristics of its constituents leading to the development of a 'Spatial Energy Management System' (SEMS) – an integration of Spatial Decision Support System (SDSS) and EMS.

The present paper reveals and emphasizes the introduction of Spatial Informatics and GIS into Electric Power and Energy Systems that will transform the power sector, which is extremely important for any fast growing developing country with huge populations like India and China.

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