Analyzing a Section of Ahmadu Bello University's Electrical Grid Using Geometric Network Analysis and Trace Function

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Keywords: Electrical Grid; Geometric Network Analysis; Trace Function; GIS

SUMMARY

The electrical grid constitutes a complex electrical power system network, encompassing generating plants, transmission lines, substations, transformers, distribution lines, and consumers. In Nigeria, these grids often rely on electric poles. However, the efficiency of electric poles is susceptible to factors such as strong winds and erosion, which can lead to pole failures and, subsequently, unplanned power outages. This study addresses various issues, one of which is the delayed response of electric utility companies to distribution network faults. The research focused on the main feeder of Ahmadu Bello University's (ABU) electricity grid and employed a Garmin ETrex20 GPS receiver to obtain coordinates (latitude and longitude) of features within the area. Attribute data of these features were collected through interviews and organized in a geodatabase. ArcGIS v10.5 Software was utilized to map the distribution of facilities, and the geodatabase's spatial attributes were analyzed. The network featured 201 poles, accounting for 88.16% of the infrastructure, 9 Ring Main Units (RMU) at 3.49%, and 18 transformers at 6.98%. This disproportion between transformers and RMUs is attributed to certain RMUs serving multiple transformers within the network. Geometric network-based flow analysis visually highlighted the features responsible for power distribution within the grid. Trace analysis using the geometric network demonstrated its effectiveness in identifying and analyzing network paths. The study also examined the value of utilizing spatial data within the utility industry and proposed potential improvements for such applications.

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1. INTRODUCTION

The generation, transmission, and distribution of electricity is the primary method used in the majority of industrialised and developing nations to supply consumers' homes, workplaces, and industries with energy. The process of producing electric power from major energy sources (such as coal, natural gas, nuclear power, hydro, biomass, etc.,) is known as electricity generation, and it is the initial step in the distribution of electricity to consumers. Power plants produce electricity, which is then transferred between electricity producers and consumers via a complicated network of substations, transformers, and power lines known as the grid. Kahinde (2019) described the electrical grid as the electrical power system network comprised of the generating plant, the transmission lines, the substation, transformers, the distribution lines, and the customers. The majority of local grids are linked together for business and reliability reasons, creating bigger, more stable networks that improve the coordination and planning of the supply of energy (EIA, 2018).

Utility companies save money when such grids are managed properly. Such grids can be managed in a variety of ways. One of the appropriate methods for managing electricity grids is to use Geographic Information Systems (GIS). GIS offer a database for spatial and attribute data about the grid's component parts, which facilitates the use of queries to easily access targeted information. Additionally, GIS can be used to model and analyse such grids. This kind of analysis makes a lot of decisions easier and faster to make. The Geometric Network Tool is one of the features of Esri's ArcGIS; it allows for the design and analysis of various networks (Esri, 2016). Similarly, road networks and public utility networks (such as those for electric, gas, and water utilities) are frequently modelled using geometric networks (Meehan, 2007).

GIS technologies have been used in many cases for utility mapping because of their numerous advantages such as spatial analyses, cost-effectiveness and efficiency, data integration, real-time monitoring, etc., therefore, employing the GIS techniques and Geometric Network tools by extension to analyse a Section of Ahmadu Bello University's Electrical Grid is highly important.

There are existing related works related to our study: Rajab (2016) carried out mapping and modelling an electrical power network on the web. Results of the interactive web-based GIS system consisted of a dynamic database and a web based user interface. Likewise, Damilola (2013) worked on geospatial modelling of electricity distribution networks for effective distribution and conservation of electricity using satellite imageries and spatial data. Furthermore, Sree and Phani's (2016) study found that a powerful tool for anticipating and controlling risk factors for any kind of utility would be the use of geographic information systems (GIS) in the implementation of utility management systems.

These electrical grids in Nigeria are formed using electric poles. On the other hand, erosion and powerful winds can damage electric poles. These elements could result in poles falling, disrupting the grid, and generating unscheduled power outages. The problem of locals stealing electricity is another. The needless delay that electric utility companies have in reacting to issues pertaining to their distribution networks is one of the issues that this study will attempt to address.

In the study area, there is no much problem with electricity theft but the grid does get sabotaged by factors like wind, rain, etc., and the unnecessary delays in responding to such faults caused by these factors is present also. Geometric network models can assist the ABU substation in facilitating load management, outage management, and system analysis. It can also help them identify affected areas in case of power outages within the minimum time possible. Any analysis that involves the flow of resources, such as electricity, gas, or water, can be modelled using a geometric network.

In this study, we analysed a section of Ahmadu Bello University's Electrical Grid by running a geometric network, to detect faulty areas within the shortest time possible. We specifically created a geodatabase of the spatial attribute of the features/facilities in the electricity grid; queried and analysed the distribution of facilities within the study area; analysed the direction of flow of electricity from station to consumers, and successfully ran the trace function on the network.

1.1 Study area

The study area is a section of the Ahmadu Bello University Main campus, Samaru Zaria, Kaduna State, Nigeria. The area to be covered is about 9.50 km in perimeter and 4.24 km^2 in area. The study area spans 11° 8'59.47"N, 7°39'55.50"E; 11° 8'14.32"N, 7°38'50.25"E and 11°10'2.35"N, 7°37'58.39"E (Figure 1). The study area was divided into two parts, the staff quarters and the main campus. The area has a lot of trees, especially in the former. The latter on the other hand has not as many trees but has a lot of tall structures. The population is sparse due to the type of settlement; it is a university quarters for its staff. It is incredibly large but well planned in road networks but for the features in the electricity grid, little can be said about the network.

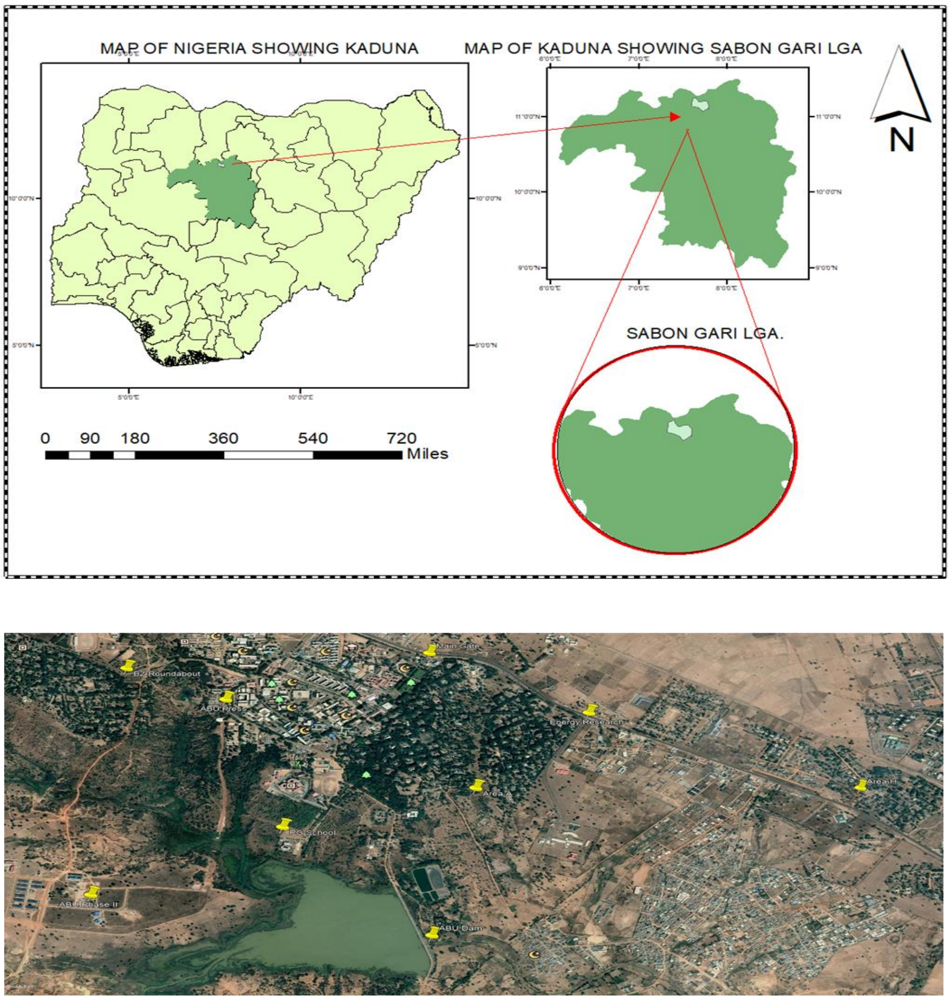


Figure 1: Study area

2. MATERIALS AND METHODS

2.1 Materials

The hardware used are a Garmin ETrex20 GPS receiver (for field work), and a Laptop computer, whereas software are ArcMap v10.3, Microsoft Office, 2016, Google Earth Pro, and ArcGeek coordinate converter. The datasets utilized for the study are shown in Table 1.

Table 1: Datasets

S/n	Data type	Data name	Data date	Source	Purpose	Description
i.	Secondary	Area Extent	2019	Google Earth	Determining the nature and extent of the study area.	Satellite imagery and perimeter coordinates
ii.	Primary	Spatial Data (E, N)	2019	*Garmin ETrex20* GPS	To create a geodatabase of the features in the network	Coordinates of the features in the network.

2.2 Method

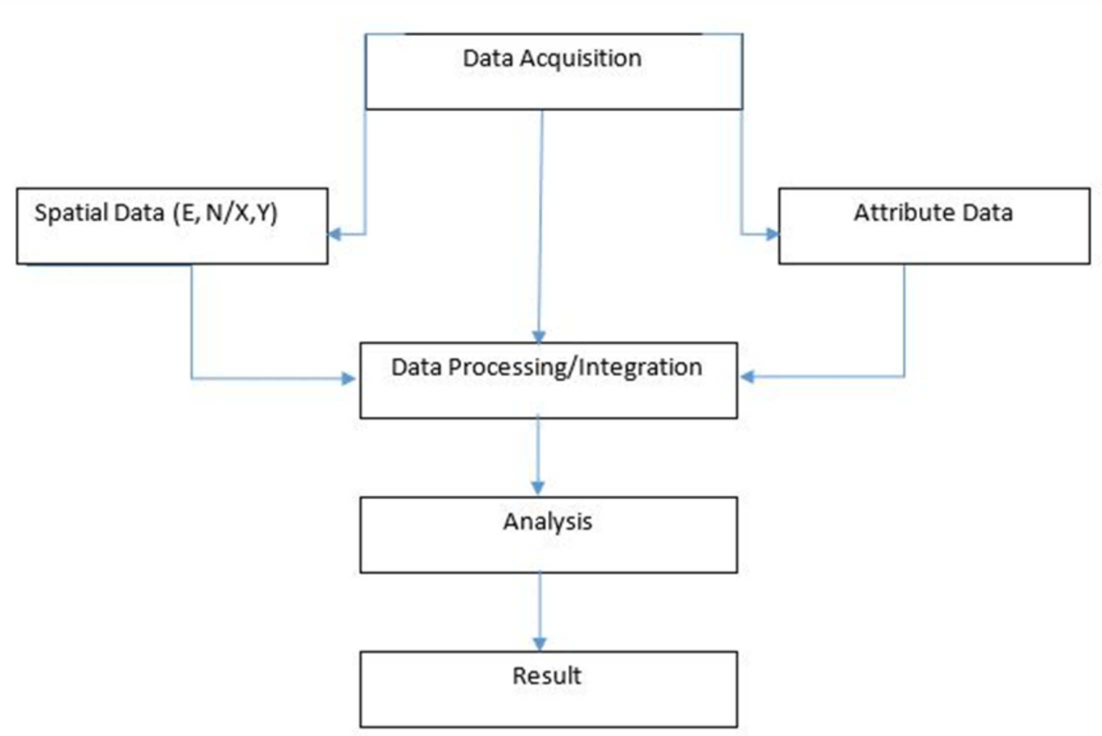


Figure 2: Methodology flowchart

2.2.1 Data Acquisition

The field data collection was planned using a satellite image obtained from Google Earth Pro. The spatial data collection (Figure 2) started from the Main Feeder at the bulk metering unit ABU Zaria, the network was followed in sequence from the Feeder to Poles to RMUs down to Transformers. The attribute data was collected alongside the spatial data and was recorded in a field book. *Garmin ETrex20* GPS receiver was used in the acquisition of the spatial data.

2.2.2 Data Processing

2.2.2.1 Categorisation and Cataloguing

The positional data of the several features involved in the network were obtained, the features have different functions so, what is meant by "*categorisation*" here is sorting the point data using different Excel sheets according to the functions of those features. The data, catalogued in Excel, was saved as CSV-MS DOS file format (*for it to be imported to ArcMap*).

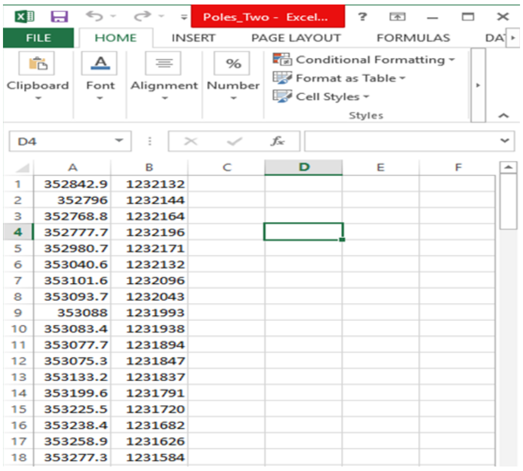


Figure 3: The catalogued data (in Excel)

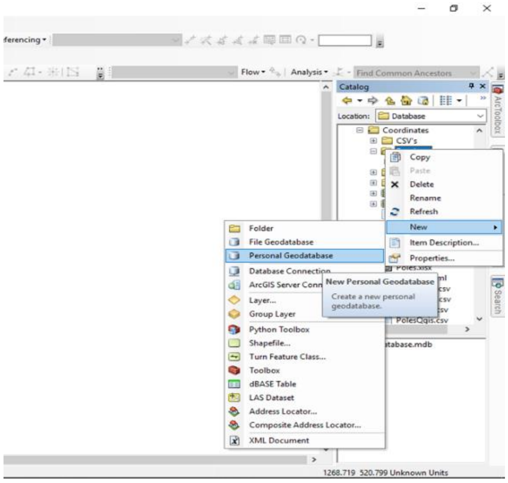


Figure 4: Creating a Geodatabase in ArcCatalogue

2.2.2.2 Processing in ArcMap.

A personal geodatabase was then created in ArcMap in which all the datasets to be used will be stored. The table containing the point data was brought into the geodatabase, and the data was displayed in ArcMap. To create a geodatabase, right-click on a folder you want to save your database in and go to new, then click on personal geodatabase.

2.3 The Geometric Network

2.3.1 Datasets

Geometric networks work with two types of features, the point data (Junctions) and the line feature (Edges). For the junctions, the x/y data acquired was used and for the edges, a new shapefile was created of a line feature that will be connecting between the junctions. A new "Feature Dataset" was then created in the geodatabase, the junction and edge datasets were imported into the geodatabase from where the geometric network is to be created.

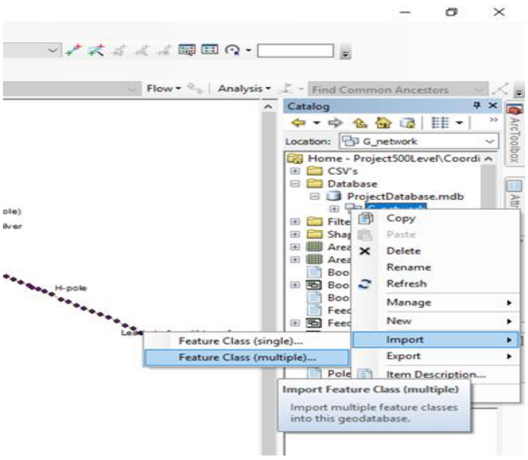


Figure 5: Feature classes import to geodatabase

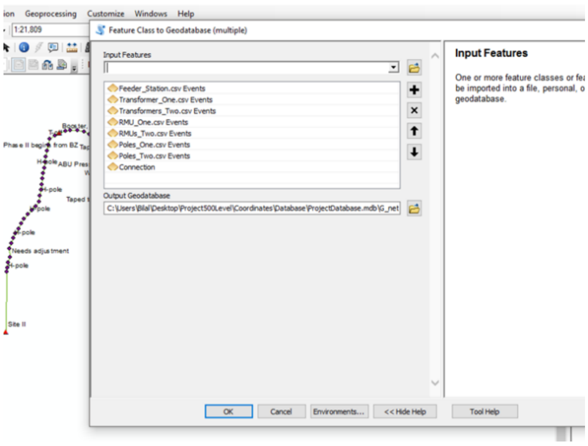


Figure 6: Output of the feature classes

2.3.2 Designing a Geodatabase Topology

Designing a geodatabase topology before creating a geometric network is not necessary but it will save you a lot of time because your network won't flow well with topological errors. To design the geodatabase topology, the feature classes to be involved must be in a feature dataset container under the working geodatabase. Then you right-click on the data set folder, go to new, and then click on topology. The *create topology* wizard will appear.

2.3.3 The Network.

ArcCatalog was used to create the geometric network. The thresholds set for the geometric network wizard are as follows: i. RMUs were set "sources"; ii. Transformers were set as "sinks", and iii. Edges were set as complex edges.

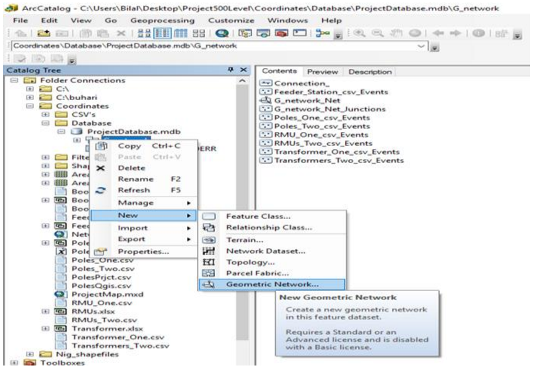


Figure 7: Creating geometric network

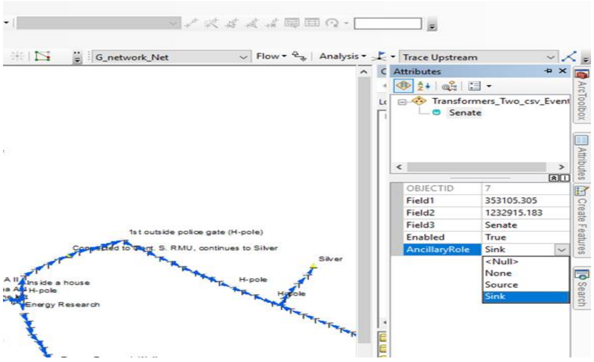


Figure 8: Setting Ancillary Role

After the network has been completed, Ancillary Roles were then set through the features attribute table, if a junction is a source or a sink then it has an ancillary role. For this to work, the editing toolbar was enabled. Setting the ancillary roles helps in calculating the direction of flow.

3. RESULTS AND ANALYSIS

3.1 The geodatabase of the spatial attribute of the features/facilities

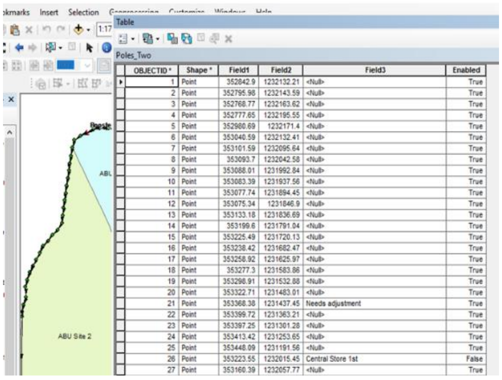


Figure 9: Geodatabase in ArcMap.

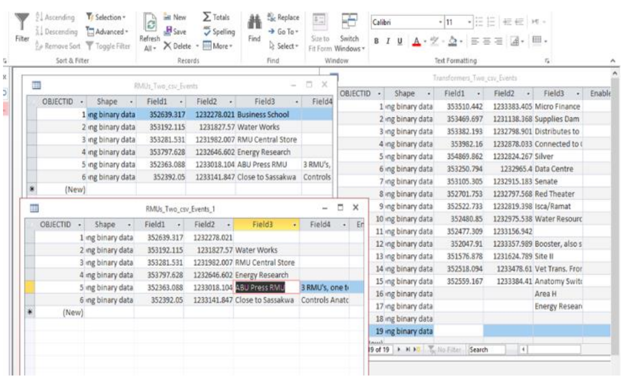


Figure 10: The Geodatabase in Microsoft Access

The geodatabase created, Figure 9: shows the view in ArcMap, and Figure 10: shows the view in Microsoft Access.

Table 2: Features involved in the network

S/n	Feature	Quantity	%
i.	Poles	201	88.159
ii.	Ring Main Units (RMU)	9	3.488
iii	Transformers	18	6.977

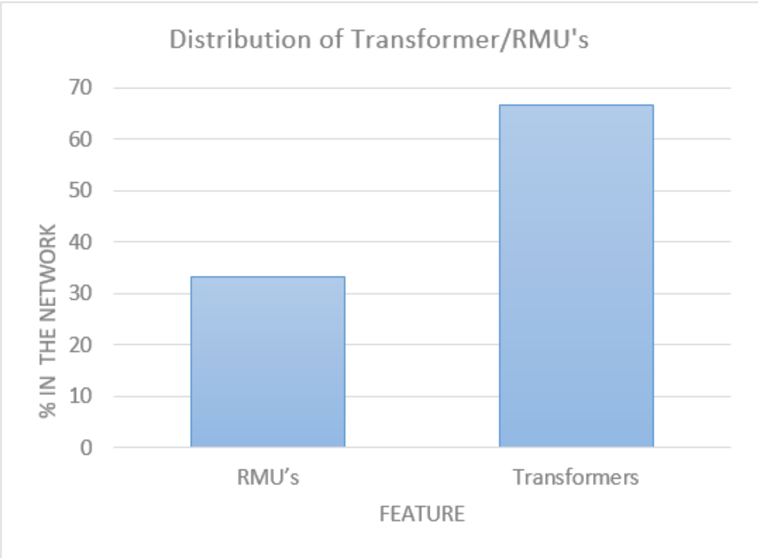
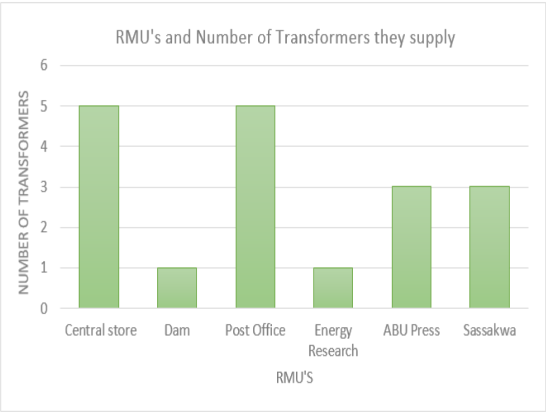


Figure 11: Transformers and RMUs Features (in %)

From Figure 11, it is apparent that the percentage of transformers is larger than that of the RMU and that is because there are RMUs that feed more than one transformer in the network. Table 3 and Figure 12 show the distribution.

Table 3: RMUs in the network and transformers they feed.

S/n	Central store	Dam	Post Office	Energy Research	ABU Press	Sassakwa
i.	Area A Part 1	DAM	Micro Finance	Energy Research	Water Resources	Anatomy
ii.	Area A Part 2		Senate building		Sassakwa	Vet. Medicine
iii.	Energy Research		Demonstration		ABU Press	ABU Site II
iv.	Silver Jubilee Quarters		Centre of excellence			
v.	Area H		PG School			



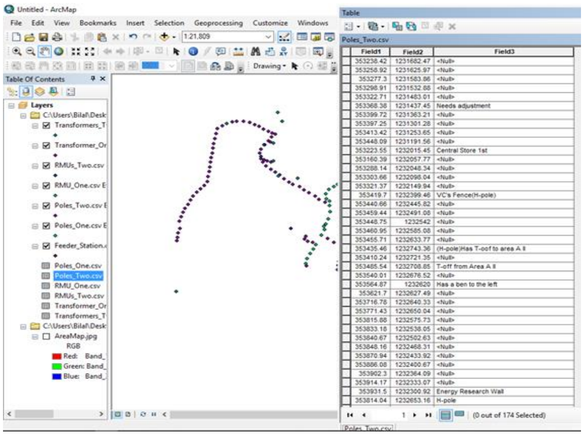


Figure 12: Distribution of transformers to RMUs

Figure 13: Point data displayed in ArcMap

Table 3 and Figure 12 as discussed earlier show how many transformers were distributed to each RMU. RMUs in the network can have several transformers hence the number of RMUs appears greater than that of transformers. We can also use this information to know which RMUs can still take more transformers. The point data displayed in Figure 13 are the features in the network. It involves the poles, transformers, RMU, and the main feeder. They were used as junctions in the network.

3.2 Flow Analysis

The direction of flow in the network shows where each RMU (Source) is sending its supply to and where each transformer (Sink) is getting its supply from. The flow can be either determinant, indeterminate, or uninitialized.

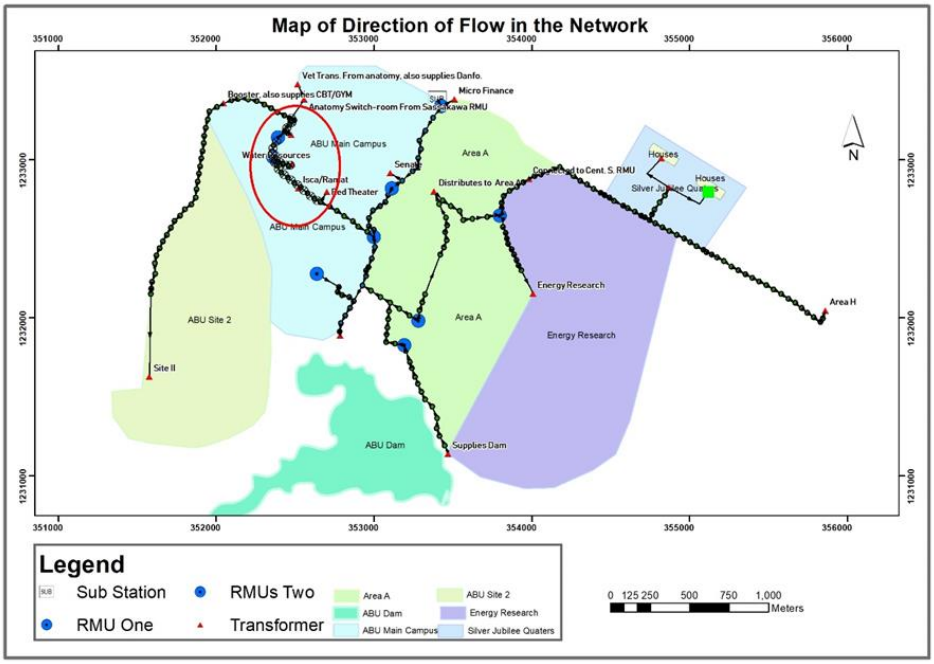


Figure 14: Flow of power

From Figure 14, it is clear that the flow in the majority of the study area has been determined except for the highlighted area in RED, which displays an indeterminate flow.

It’s important to point out that there are two ways to achieve a flow in a geometric network, there is the one used in the study i.e. using sources and sinks and the second is using the digitized direction of edges. Using the latter, there can’t be any problem of indeterminate flow like in Figure 14, but it does not allow for tracing. It is possible to trace the sink to its source and vice versa using the flow function but it is not possible to isolate a single flow, this can only be done using the trace function.

3.3 The Trace analysis

The trace analysis is the most useful and most challenging feature contained in the geometric network, it is also vital to this study because as mentioned earlier, the flow analysis will let you trace each sink to its source and vice versa following the direction of the arrow alone, but it doesn’t allow for isolated traces. That is the main function of the trace analysis. Examples of traces from the study are shown in Figures 15 and 16:

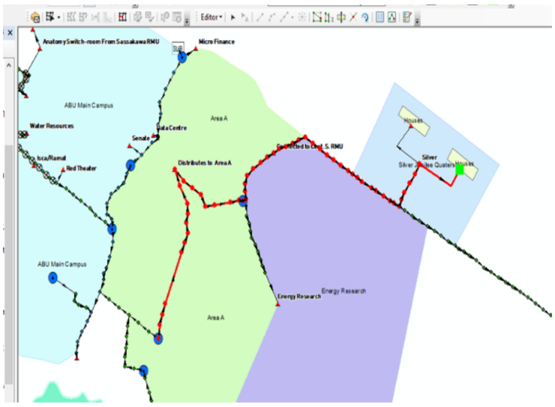


Figure 15: Tracing a house in Silver to its RMU.

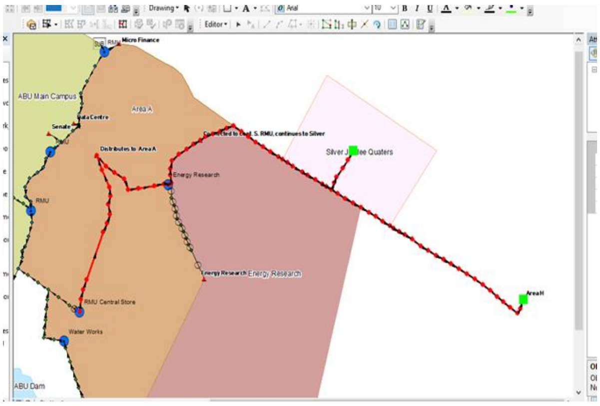


Figure 16: Trace from Area H transformer to its RMU.

In Fig 15 the tracing flag (the green square) was set at a house in Silver Jubilee quarters and traced down to its source RMU, and it worked. Likewise, in Fig 16 the flag was set in Area H transformer and Silver Jubilee Transformer and traced down to their source RMU.

The trace function enables the user to isolate a trace from sinks to sources. Like in Figures 15 and 16, from the trace in RED, it is easier to locate the RMU that feeds Silver and Area H respectively. However, there are flaws encountered both in setting the flow and also in the course of running the trace. The flaws are not all pertinent to the network Grid itself but also the inefficiency of the Tool in question. Some of the flows are shown in Figures 17 and 18:

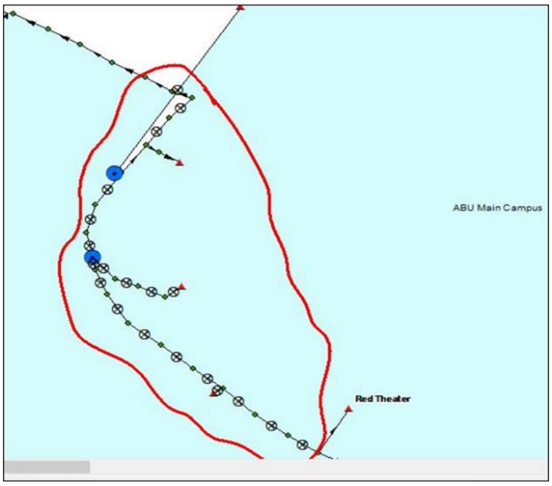


Figure 17: An indeterminate flow.

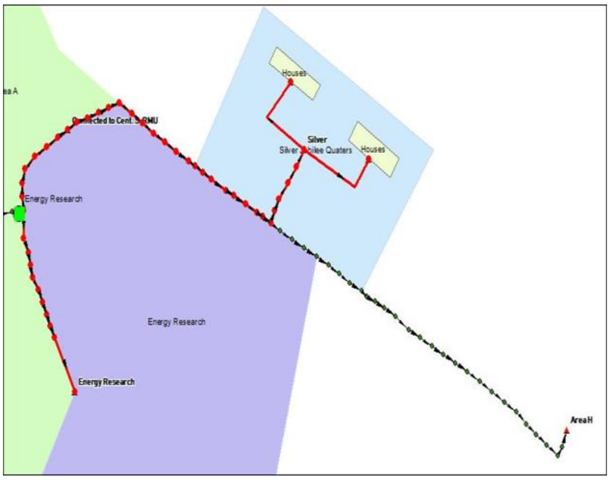


Figure 18: A trace error from a multi-directional flow.

In this part of the network (Figure 17), two RMUs are involved, ABU Press RMU has three outputs, one to water, one to Sassakwa, and one to Press itself, and the second, Close to Sassakwa outputs to Anatomy, Chemical Engineering, ABU phase II and part of faculty of Veterinary medicine. So the two RMUs output to 7 transformers altogether. Geometric Networks do not allow for multi-directional flow thus, wherever there is one it will be set as an indeterminate flow just as the highlighted area in Figure 15 and Figure 16. Another example from the study is shown in Figure 18 where the flow coming from a certain RMU is supposed to feed silver and then continue to the subsequent transformer at Area H but this error prevented the trace from showing that, hence it stopped at Silver and not continuing to Area H.

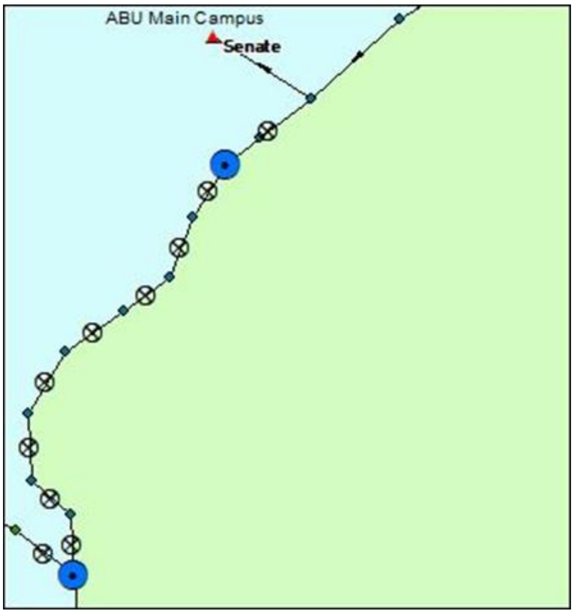


Figure 19: A clash between two RMU’s (sources).

Another error encountered is in a situation where an RMU feeds another RMU (Figure 19). The problem here is that an RMU is a source in the network and a Geometric network does not allow for flow from one source to another source. This kind of error is probably because of the kind of arrangement of the network Grid.

The study made use of a geodatabase for virtually all its analysis. The creation of the geodatabase was achieved using the Esri ArcGIS suit. All the spatial and non-spatial data in the study were stored in the geodatabase. Analysis of the distribution of some important features in the network was also achieved through the use of graphs. Regarding this, Figure 12 shows that there are RMUs that can still take more transformers.

The study also showed the application of Esri's ArcGIS Geometric Network tool on a real existing electric utility network. The network model was built exclusively using the Esri ArcGIS Geometric Network tool. The flaws in it have been recognised as well as the advantages it incorporates. The flaw in the flow analysis is not at all pertinent to the organisation of the network Grid on the ground itself but rather the inefficiency of the Tool in question. The error in the flow analysis can be avoided using the digitized direction of edges.

The trace function was also run successfully in some areas while there are errors in some areas. It can be said that the geometric network when it comes to tracing, it's not 100% efficient.

4. CONCLUSION

During this study, a few problems were encountered. Firstly, the acquisition of some of the spatial data was a bit challenging because some of the features were in inaccessible areas. Secondly, the features that are very close to each other can't be distinguishable during plotting due to the instrument used for data collection. However, these were surmounted.

The importance of the use of GIS in the utility industry can be perceived through the study. Geometric networks are not 100% efficient alone. The model created in this study is helpful but it is not efficient enough because not all the traces were successful due to the inefficiency of the tool. The three basic categories of GIS functions, DBMS spatial analysis, and visualization in a single suit created an environment that is better than what is currently in use i.e. paper maps and office files in managing records. It is recommended that the use of network analysis should also be considered because determining the shortest routes possible to a particular place is vital for utility companies because it saves time and cost.

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BIOGRAPHICAL NOTES

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