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ORIGINAL RESEARCH ARTICLE

SPATIAL MODELLING AND ANALYSIS OF AN ELECTRICAL DISTRIBUTION SYSTEM

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ABSTRACT

The distribution of electrical energy to end-users in Nigerian communities is faced with diverse spatial problems leading to low voltage, overload on equipment, difficulties in fault tracing and delay in fault clearing. The traditional management system is not only manual but also has flaws such as difficulties in searching and updating previous records as well as no real-time information on their distribution assets. In this study, a geospatial technique was employed for effective management of the electricity distribution system in Malete, Kwara State, Nigeria. Spatial information of distribution asset was collected from the field and used in the structural modelling of the distribution network in the ArcMap software. Analysis of the model and the available information showed that 80 % of the transformers were not properly located at the centroid of the load. The span of the network fairly conformed to standard as only 45.73 % were within 45-50 m. The result also showed that 40 % of the transformers were overloaded with an unbalanced load, hence the need for restructuring of the network

1.0 Introduction

One of the major factors that have differentiated the modern man from his ancestor is the ability to effectively manage energy. In recent time, electric energy has become the most available form of energy used in industries, domestic homes, recreation, transportation etc. It is one of the intensive basic need for smooth, meaningful and productive economic life, as the economic growth of any nations largely depends on the effective management and control of the available electrical power (Adejoh et al., 2015; Avila et al., 2017; Kaseke and Hosking, 2013). As a result, there is a need for power supply authority to keep a comprehensive and accurate inventory of the distribution assets and their spatial location. This will assist in normal service provision, an extension of the network, forecasting, fault detection and recovery, and undertaking maintenance (Fleeman, 1997; Zhang et al., 2008)

In recent time, the government of Nigeria embarked on putting an end to the long-time electrical power crisis in the country by setting up a roadmap. Much attention is being given to increase the generation potential and ensure a reliable transmission network (Biobaku, 2010). Unfortunately, the losses in the distribution network reduce the supply efficiencies. Likewise, the lack of proper information on the distribution network reduces reliability. Despite all effort, the nation is yet facing unpredictable power outages, low voltage, delay maintenance and poor quality of supply (Olaparodi, 2016). In such a situation, research efforts should not focus only on maintaining an efficient power generation, rather effort should be made to transmit and distribute generated power with minimum possible losses.

Without appropriate record-keeping and observance of the transmission and distribution system, efficient functioning of the generated power cannot be achieved. According to Pickering et al. (1993), proper knowledge of an existing asset is important for efficient operation on an electrical system. Therefore, this study presents the spatial modelling and analysis of an electrical distribution network of Malete, a community hosting Kwara State University. It lies between latitude 8.711° N – 8.702° N and longitude 4.465° E – 4.480° E. The study area is as shown in Figure 1. The work involves collation and development of a database of relevant information about the distribution network and their conditions. The existing network was modelled using ArcMap GIS software. The model was analysed in order to obtain the consumption trend and other factors affecting supply efficiency.

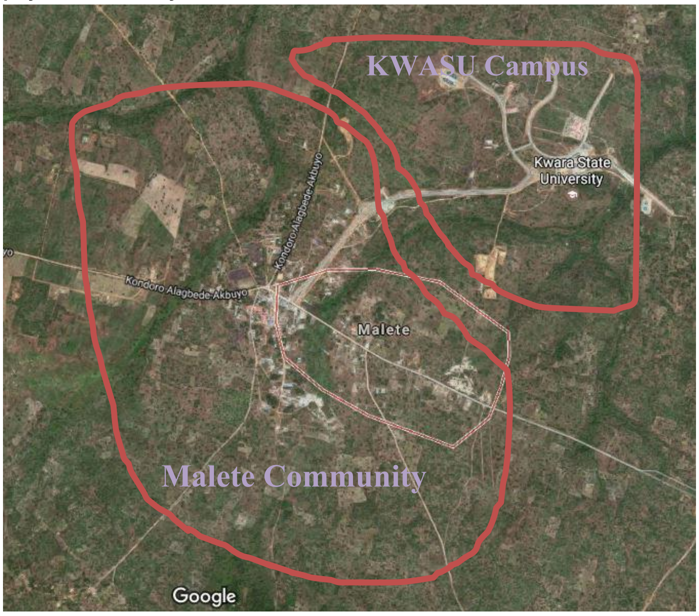

Figure 1: Map of Study Area

1.1 Literature Review

Geographic Information System (GIS) collects, stores, retrieve, analyse and display geographical data. It combines different layers of information about a place for better understanding and depending on the purpose. The software can capture, store and update, manipulate, analyse, and display geographic information. It is typically used to represent maps as data layers that can be studied and used to perform analyses (Rezaee et al., 2009).

The power of GIS over paper maps is its ability to select the information needed depending upon the intended application (Vijay, 2001). The database which is the most important asset of an organization can be divided into two main various data types: spatial data that describe the location and the shape of geographic features and spatial relationship of map features (Blagajac et al., 1998). Attribute data are known as descriptive information of the map features. GIS software and hardware are used in Electrical Power System as tools for storing, analysing, interpreting, updating, displaying information, professional's designs and maintaining the system.

The Global Positioning System (GPS) is one of the main building blocks, helping in the 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 the space that are picked up and identified by GPS receivers. Each GPS receiver then provides the three-dimensional location (latitude, longitude, and altitude) plus the time. Hence, GPS can provide any point on earth with a unique address and its precise location (Hoque, 2016; Parkinson and Spilker, 1996; Bradford, 1994; Walton and Black, 1999).

GIS has been used for modelling of distribution facilities such as poles, power lines and transformers in different places in the world (Mathankumar and Loganathan, 2015; Zhang et al., 2008). This has assisted in managing problems arising from the complexity of the distribution system and providing means of keeping up-to-date information on the assets (Damilola, 2015). It can also enhance the efficiency and reliability of the power system (Kanmani & Babu, 2014; Simon and Cherere, 2011).

This method has been very welcomed by the supply authority in Nigeria in the analysis of the distribution network. Salawudeen and Rashidat (2006) reported such activities on the national distribution system, focusing on locating and mapping distribution facilities via a collection of geometric and attributes data. The collated data studied and analysed in order to understand the condition of the distribution network. This was reported by (Adejoh et al., 2015) where GIS was used to discover that the 500kVA transformer in a given location was overloaded by 5.12%.

In this study, the effort is not only made to model the distribution system using GIS but also to analyse the interconnections, loading on transformers and provision of a better location for the transformers to reduce power loss and maintain the supply voltage within an acceptable limit.

2.0 Methodology

The methodology used based on data acquisition through field survey. Two types of data were collected; namely spatial data and non-spatial data. Spatial data included the coordinate (latitudes and longitudes) location of transformers as well as high and low-tension poles. Geographical coordinates were obtained using a hand-held GPS device.

In addition to the spatial information, non-spatial data involving consumer's connection details, transformer attributes (as presented on nameplates), line voltages, instantaneous current demand, lines conductor size and type were also acquired.

2.1 Data Modelling

The data collected was modelled using ArcMap software. A differential correction was performed on the spatial data thus captured. For better visualization, the vector map of the network was overlaid on the digital base map or a satellite raster image. In addition, service lines and customer connection point were digitized. A file geodatabase was

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involved with dataset projected using a coordinate system. The file geodatabase contains features named as high tension (HT) Pole, low tension (LT) Pole, transformers, isolator, primary lines and secondary lines. The coordinate point of the transformers, high and low tension poles acquired was incorporated into the geodatabase using add absolute X, Y coordinate in ArcMap environment, and non-spatial data (transformer details) were linked together with spatial data as attributes.

2.2 Data Analysis

The data collected was used in Microsoft Excel to developed data Tables for spatial distance calculation, centroid calculation, load profile and line losses calculations.

2.3 Spatial Distance

The pole-to-pole distance for both high tension and low-tension poles and estimation of the distance between low-tension poles and transformers were calculated using haversine formula. The estimate was necessary in order to obtain the length of the conductors from the transformer to consumers for the estimation of line losses. Equations 1 and 2 show the relationship between the haversine formula and the distance between two points in the great sphere.

$$\mathrm{hav}\left(\frac{d}{r}\right) = \mathrm{hav}\left(\varphi_2 - \varphi_1\right) + \cos\varphi_1 \cos\varphi_2 \,\mathrm{hav}(\varnothing_2 - \varnothing_1) \quad (1)$$

$$d = 2r\sin^{-1}\left(\sqrt{\sin^2\left(\frac{\varphi_2 - \varphi_1}{2}\right) + \cos\varphi_1 \cos\varphi_2 \sin^2\left(\frac{\varnothing_2 - \varnothing_1}{2}\right)}\right) \quad (2)$$

Where: hav represents the haversine function, d is the distance between two points (along a great circle of the sphere, r is the radius of the sphere i.e. radius of the earth $r = 6371\mathrm{km}$, $\varphi_{1,}$ φ_2 are latitudes of points in radians and $\varnothing_1$, $\varnothing_2$ are longitudes of points in radians.

2.4 Calculation of Centroid Location

In order to locate the transformer at the centre of the load, the following relationships in equations 3 to 7 were developed.

$$I_p = i_a \times N_p \quad (3)$$

where I_p is the current at a pole, i_a is the average sampled current and N_p is the number of buildings on the pole

$$L_m = I_p \times L_p \quad (4)$$

where L_m is the mean on latitude, and L_p is the latitude of the pole (degree).

$$\mathcal{L}_m = L_m \times \mathcal{L}_p \quad (5)$$

where $\mathcal{L}_m$ is the mean on longitude, and $\mathcal{L}_p$ is the longitude of the pole (degree).

$$C_L = \frac{\sum L_m}{\sum I_p} \quad (6)$$

$$C_{\mathcal{L}} = \frac{\sum \mathcal{L}_m}{\sum L_m} \quad (7)$$

where C_L is the centre on latitude(degree) and $C_{\mathcal{L}}$ is the centre on longitude (degree).

3.0 Result and Discussion

The following Tables 1 and 2 show the data collated for transformers in Malete community and KWASU campus. The tables present the transformer locations, power in kVA, the voltage in kV, current in Amperes and number of output legs.

Table 1: Malete Transformer Network Data

MALETE TRANSFORMERS							
S/N	LOCAL NAME	φ (°)	∅ (°)	kVA	V (kV)	I(A)	Leg
1	West-End	8.707233	4.470674	500	33/0.415	8.75/695.6	3
2	Lambo	8.703356	4.467826	300	33/0.415	5.25/417.4	2
3	Boyi Hotel	8.708141	4.468712	100	33/0.415	1.75/139.1	1
4	Malete Park	8.710603	4.463728	500	33/0.415	8.75/695.6	2
5	Amina Castle	8.709705	4.463622	300	33/0.419	5.25/417.4	1
6	Sequence	8.70695	4.463117	300	33/0.415	5.25/417.4	2
7	Safari 1	8.70614	4.46546	500	33/0.415	8.75/695.6	2
8	Safari 2	8.70259	4.46519	500	33/0.415	8.75/695.6	2
9	Millionaire Com Tower	8.6977	4.46421	300	33/0.415	5.25/417.4	1
10	KWASU Roundabout	8.70956	4.465918	100	33/0.415	1.75/139.1	1

Table 2: KWASU Transformer Network Data

KWASU TRANSFORMERS							
S/N	LOCAL NAME	φ (°)	∅ (°)	kVA	V (kV)	I (A)	Leg
1	KWASU Substation	8.717232	4.47217	5000	33/11	87.48/262.43	1
2	Admin	8.718771	4.485385	500	11/0.415	26.25/695.6	3
3	Staff Quarters	8.716247	4.490926	300	11/0.415	15.75/417.4	1
4	AA Block	8.721514	4.4862	500	11/0.416	26.25/695.6	2
5	Works	8.723876	4.481192	500	11/0.417	26.25/695.7	2
6	General Hostel	8.725109	4.477752	300	11/0.418	15.75/417.4	2

3.1 GIS Modelled Network

Using the ArcMap software, the data in Tables 1 and 2, as well as the poles spatial data, a structural model of the Malete community distribution network and that of KWASU campus, were developed. Figure 2 presents the GIS model of the Malete community distribution network while Figure 3 presents that of KWASU campus. The networks show consumer points where customers connect to the service lines, the spatial location of electric poles, and transformers with their respective up-risers connecting the

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transformers to the service lines. The network structures exist on paper and sometimes they do not exist. Whenever there is an extension on the network, the structure has to be drafted again or omitted. As a result, the physical network differs from what is available. This makes planning and maintenance more difficult than necessary. This the software-based network structure of Figures 2 and 3, the network can be studied used during fault tracing, maintenance and planning for an extension.

3.2 Voltage Profile

Figures 4 and 5 show the voltages at sampled low-tension poles of West-End and Sequence Transformers respectively. There is a significant drop in voltage down the line; it is because of the long distance between the consumers and the transformer, resulting in high losses along the line. Thus necessitating the need to minimise the distance between the consumers and the transformer on such a feeder.

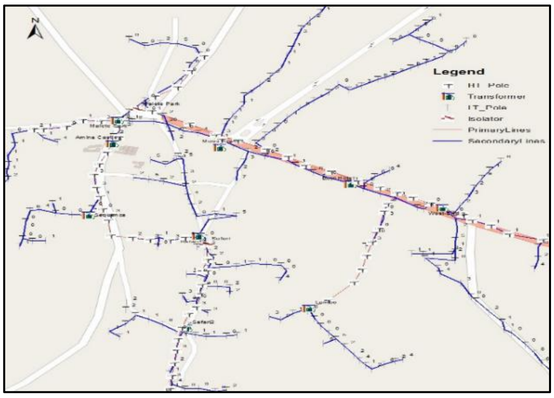


Figure 2: Distribution Network System of Malete Community

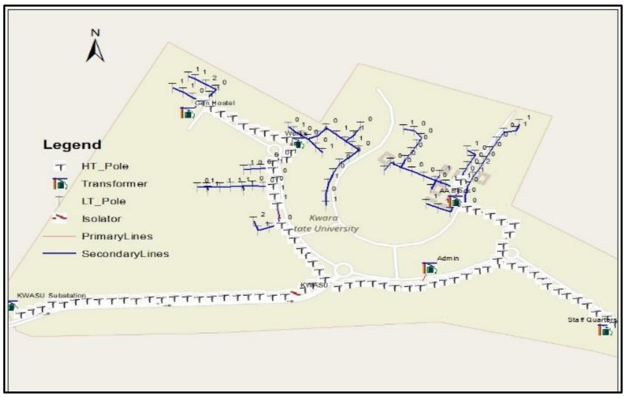


Figure 3: Distribution Network System of KWASU Campus

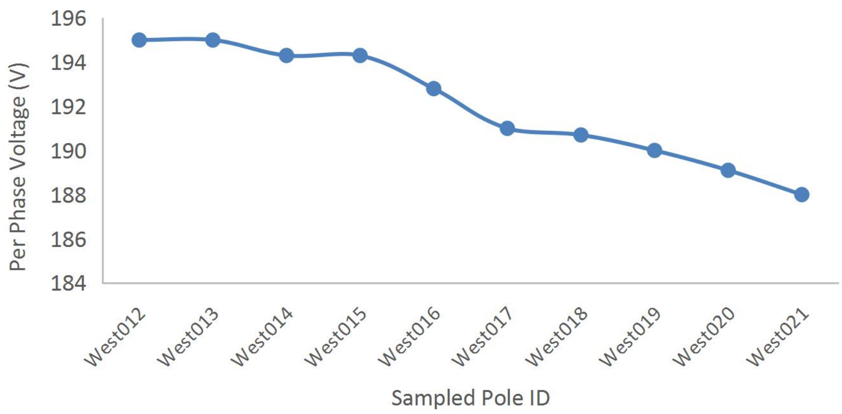


Figure 4: Measured Voltage Profile of West-End Network Leg 1

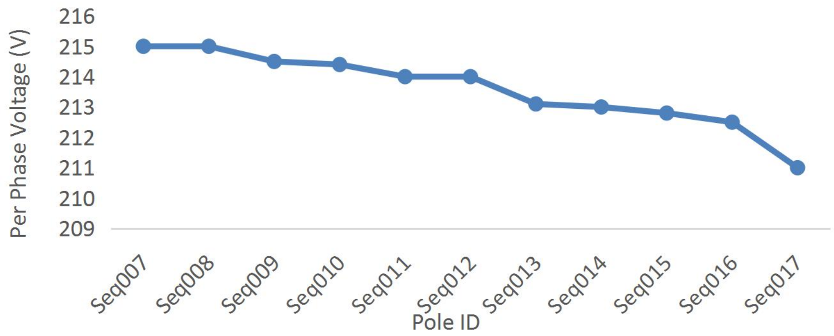
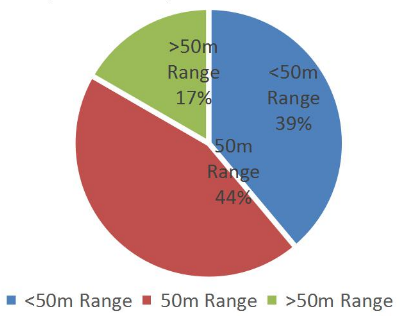


Figure 5: Measured Voltage Profile of Sequence Network Leg 2

3.3 Low Tension (LT) Pole Positioning

The charts in Figures 6 and 7 show the percentage of ranges of the span between LT poles. Keeping the span uniform in length prevents the weight of the conductors on one side from pulling the pole over. As the conductor heats up, it lengthens due to thermal expansion, and the conductor sags closer to the ground. IEEE standard of spanning of LT poles is 50 m. On the contrary, the network structure of Safari Leg 2 does not fully comply with the standard. Only 44% are within the 50 m range, 17% are above this standard range while 39% are below. Similarly, the network of Safari2 Leg 1 has only 21% of the pole-to-pole distance complying with the standard.



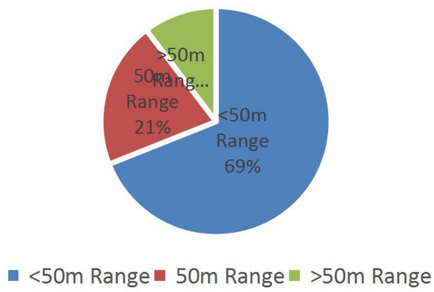


Figure 6: Pole-to-Pole Distance Shorting of Safari1 Leg 2

Figure 7: Pole-to-Pole Distance Shorting of Safari2 Leg 1

From Table 3, the structural configuration of LT pole network shows that 53.33 % of the pole-to-pole distance is 40 m and below, 45.73% pole-to-pole distance is between 41 m and 60 m and 3.6% has a pole-to-pole distance of 61m and above. This falls slightly below the recommended standard of pole-to-pole distance of 50 m for LT poles.

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Table 3: Overall Network Pole-to-Pole Distance Shorting

Network	LEG	<50m Range (%)	50m Range (%)	>50m Range (%)
Sequence Network	Leg1	50	50	0
	Leg2	64	36	0
Safari1 Network	Leg1	73	27	0
	Leg2	39	44	17
Safari2 Network	Leg1	69	21	10
	Leg2	60	40	0
Malete Park	Leg1	41	56	3
	Leg2	52	42	6
West-End	Leg1	39	46	15
	Leg2	61	37	2
	Leg3	43	57	0
KWASU Works	Leg1	61	36	1
	Leg2	44	56	0
KWASU AA Block	Leg1	44	56	0
	Leg2	18	82	0
Average		50.53	45.73	3.6

Nominal and Estimated Power Loading

The average load on five identified community transformers in Malete were estimated. The estimated power and nominal ratings are presented in Table 4. Similarly, Figure 8 shows the transformer loadings as compared with the rated (nominal) power in kVA. The chart shows that West-End and Malete Park transformers are overloaded with 27.713kVA and 17.189kVA at peak level. The West-End and Malete Park transformers are already overloaded. The load on the two transformers has to reduce in order to prevent an explosion.

Table 4: Loading on Distribution Transformers

Transformer	kVA Rating	Estimated Load Current (A)	Node Voltage (V)	Total Line Losses (kW)	Estimated Loading (kVA)
West-End	500	2398.70	220	84.05	527.71
Malete Park	500	2350.86	220	59.56	517.18
Safari2	500	1254.43	220	35.91	275.97
Safari1	500	1659.43	220	48.25	365.07
Sequence	300	961.22	220	5.05	211.47

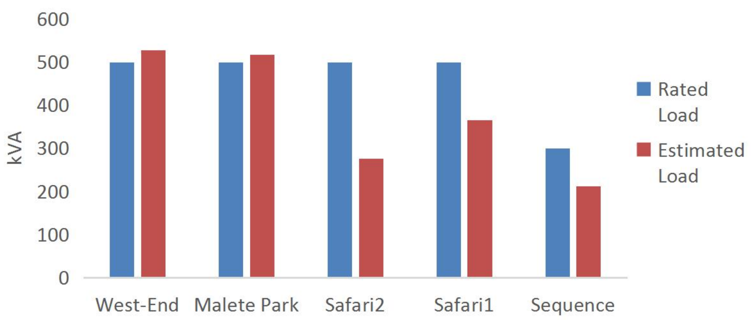

Figure 8: Comparison of Estimated Loading and Nominal Power of Transformers

3.4 System Improvement

In order to reduce line loss and voltage drop at the consumer terminals, it is appropriate to relocate the transformers to the centroid of the load. Table 5 shows the estimation of centroid location on Sequence transformer network. The centroid analysis helps to determine the shortest possible length of connection to the transformer to reduce the voltage.

With centroid analysis, transformers can be centrally located with respect to the load area being served as this minimises the length of the distribution lines connecting the transformers to the loads, thus reducing the numbers of electric poles, cost of cable will be reduced, the line resistance will be reduced and also distribution losses will be minimised.

Table 5: Sequence Network Load Centre Data Calculations recording

Pole I	Current (A) at a Pole	Mean on Latitude	Mean on Longitude
Seq001	20.8	181.1102	808.3309375
Seq002	31.2	271.6568	1212.562038
Seq003	20.8	181.1089	808.3652114
Seq004	10.4	90.55966	404.2003819
Seq005	41.6	362.2528	1616.835677
Seq006	31.2	271.7049	1212.681407
Seq007	31.2	271.6575	1212.344781
Seq008	10.4	90.55311	404.0860181
Seq009	10.4	90.55706	404.0973145
Seq010	41.6	362.2179	1616.241429
Seq011	20.8	181.1081	808.0807803
Seq012	31.2	271.6494	1212.036929
Seq013	52	452.7333	2019.982891
Seq014	20.8	181.0858	807.9525032
Seq015	41.6	362.1679	1615.964357
Seq016	10.4	90.54209	404.0169051
Seq017	10.4	90.5398	403.9559933
Summation	436.8	3803.205	16971.73555
Transformer Centroid		8.706972	4.462482184

Figure 9 shows the chart of the network of sequence transformer, being the smallest network (it consists of fewer LT poles and conductors) in the system. The transformer location is far away from the load centre. Yellow point (8.707° N, 4.463° E) represent the current location of the transformer while deep brown colour point (8.707° N, 4.462° E) represent the proposed location.

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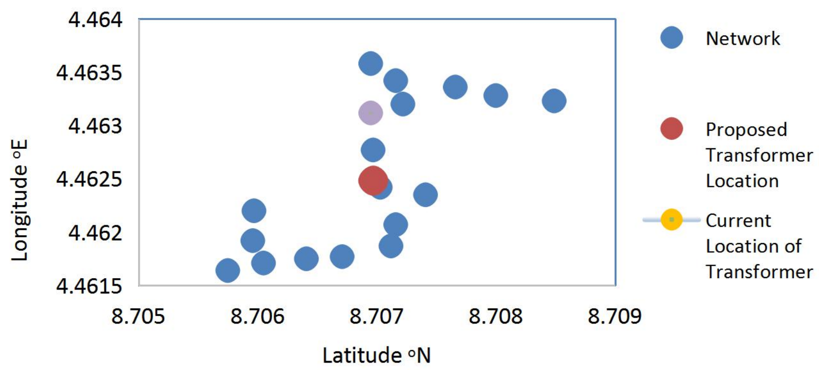

Figure 9: Sequence Network Showing Proposed Location of Transformer

Figure 10 shows the chart of Safari1 network, the current position (8.706° N, 4.465° E) of the transformer is indicated with point yellow in the network, while proposed position (8.707° N, 4.465° E) is indicated with point red. The distance between the current and proposed position is 46.27 m.

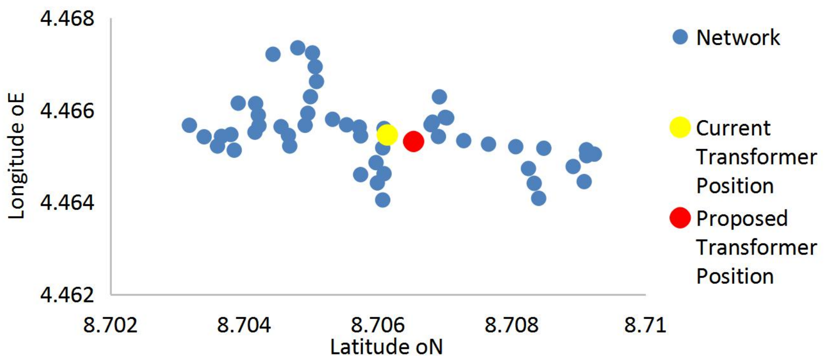

Figure 10: Safari1 Network Showing the Proposed Location of Transformer

Figure 11 shows the chart of Safari2 network, the current position (8.703° N, 4.465° E) of the transformer is indicated with point yellow in the network, while proposed position (8.701° N, 4.465° E) is indicated with point red. The distance between the current and proposed position is 172.482 m. This transformer is far away from being near the load centre and need relocating.

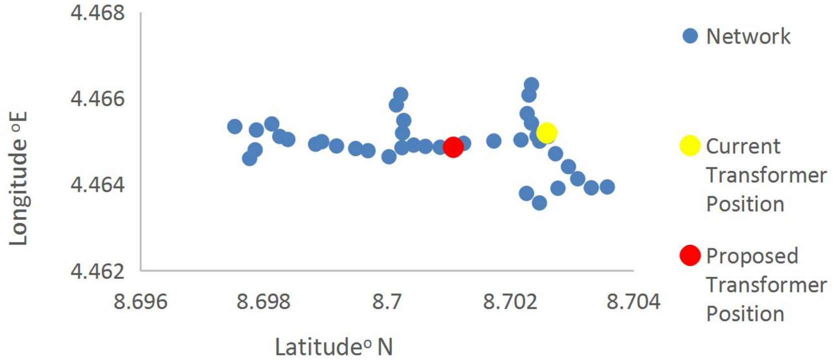

Figure 11: Safari2 Network Showing the Proposed Location of Transformer

Figure 12 shows the chart of Malete Park network, the current position (8.710°N, 4.463°E) of the transformer is indicated with point yellow in the network, while proposed position (8.711°N, 4.465°E) is indicated with point red. The distance between the current and proposed position is 167.73m. Thus, the transformer is far away from being near the load centre.

Figure 13 shows the chart of West-End network, the current position (8.707°N, 4.471°E) of the transformer is indicated with point yellow in the network, while proposed position (8.707°N, 4.471°E) is indicated with point red. The distance between the current and proposed position is 6.29m. Thus, the transformer is approximately at the load centre.

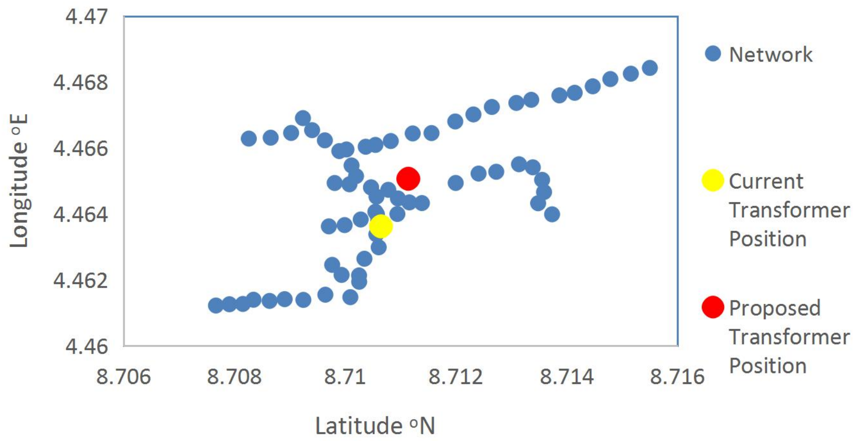

Figure 12: Malete Park Network Showing the Proposed Location of Transformer

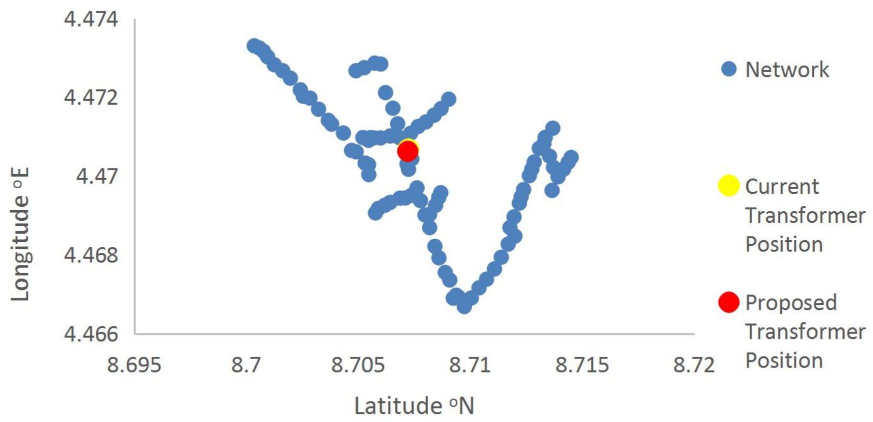

Figure 13: West-End Network Showing the Proposed Location of Transformer

4.0 Conclusion

Improvement of the performance of distribution systems to meet the required target is a matter of selecting the most effective and appropriate technology with the right operating practices. In addition, it is not sufficient to analyse how a portion of the network may be modified to improve its performance today, rather the determination of the optimal solution based on the future demand scenario.

Since the distribution network of a power utility has a geographical reference, it is beneficial to create the network on a GIS map and constantly update the same as per field parameters. With periodic updating and monitoring, integrating between

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distribution system data and GIS can be used for energy audit, load management, network planning and analysis; determining the optimum, shortest, and most economic path for transmission and distribution lines; forecasting and predicting the amount of power needed in the future which leads to prioritizing projects and control the demand growth.

This study has provided a software model of the entire Malete distribution network layout and loading characteristics. In order to reduce voltage drop at customer ' s terminals, each of the community distribution transformers needs to be located at the load centres. The loads on the Malete Park and West-End transformers have to reduce, such as to prevent an explosion. If relocation of transformers seems difficult to achieve, the network can be routed such as to reduce losses or a new transformer should be installed.

For the future, electrical engineers in the power utility industries should be trained on the use of GIS. In addition, GIS can be used in more application in an electrical system like real-time wide-area measurements using GPS as a trigger.

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