African Journal of Applied Research
Vol. 11, No. 2 (2025), pp.153-168
http://www.ajaronline.com
https://doi.org/10.26437/ajar.v11i2.995
Received: January 23, 2024
Peer reviewed: May 10, 2024
Revised: November 27, 2024
Published: April 2025

DETERMINING THE CONTRIBUTING FACTORS IMPACTING TECHNICAL LOSSES OF A SECONDARY DISTRIBUTION NETWORK

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ABSTRACT

Purpose: The need to investigate how much each factor contributes to the total distribution of technical losses is evident. This work seeks to find the extent of each possible factor's contribution.

Design/Methodology/ Approach: The research is designed as an experimental-quantitative. 40 randomly selected LV networks in urban, rural and metropolitan areas were modelled on the OpenDSS platform, and steady-state load flow studies were carried out. 14 no. predictors were then extracted as input to a regression analysis to formulate a regression equation that could be used to develop a loss reduction strategy for each network.

Findings: It has been identified that seven predictors are responsible for high technical losses. Based on the statistical significance of the predictors, they could be categorised into three categories: Average Phase Current and Average Load Power Factor, which fall within the first category. Average line Resistance (Ohms/km) and % Voltage Imbalance fall within the second category. The third category's predictions are the Equivalent Load Distance (km), Average Bus Voltage (V) and Line Average Percentage loading.

Research Limitation: This work has limitations, such as the customer load profile not being available and losses related to transformers not being considered. Some equipment's electric characteristics were unavailable, so similar ones were used. However, these limitations do not distort the results of this research.

Practical Implication: Therefore, a more appropriate strategy for loss reduction could be formulated by determining the characteristics of individual networks.

Social Implication: Reducing these losses lessens the overall demand for power generation, leading to lower greenhouse gas emissions and reduced environmental impact. This supports broader sustainable development goals and helps meet national and global climate targets.

Originality/Value: Every network has peculiar characteristics; therefore, a generalised loss reduction strategy will not yield the needed results for all circuits. A regression expression has been made to serve as a guide in determining the primary causes of high technical losses of any LV network.

Keywords: *Circuit Length. load resistance. network. predictors. technical losses*

ISSN: 2408-7920

Arca Academic Publisher

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INTRODUCTION

Electric power generation deficiency results in a power crisis, which has become a perennial challenge in developing countries, with increasing severity that threatens the economic growth and transformation of those countries. The resulting load shedding retards growth in industrial activity, job and income generation. This situation is caused by insufficient power reaching the electricity consumers. Electrical India (2018) states that some power produced at generation gets lost during transmission and distribution.

Ohm's law is a relationship between three physical phenomena: current, voltage, and resistance. Current is defined as the flow of positive charge from a point of higher potential to that of a lower potential, and its unit is ampere (A). Voltage measures the electric potential an object possesses for a charge. By applying a voltage, work is done on the charge, which enables the movement of the charge known as current flow. Another measure is the resistance, which is defined as the opposition to current flow and is denoted as R with a unit of ohms (Chavanne, Bruère, & Frangi, 2018; Martínez-Sykora, De Pontieu, Hansteen, & Carlsson, 2015)

Kirchhoff's laws are fundamental to circuit theory. They quantify how current flows through a circuit and how voltage varies around a loop in a circuit. The German physicist Gustav Kirchhoff first described them in 1845. They state that at any node in a circuit, the sum of currents moving towards the node equals the sum of currents leaving the same node.

On the other hand, Kirchhoff's voltage law (KVL) states that the sum of all voltages around a closed loop in any circuit is equal to zero. Combining the two Kirchhoff's laws forms the fundamentals of any circuit analysis.

Jain and Kanwar (2021) and Olusanya et al. (2024) argued that technical loss does occur at transmission lines, power transformers, and feeders and depends on the square of the current flowing in the line ($I^2 R$). Unisearch (2003) stated that in a distribution system, line losses are high when loads are connected at the end but lower when the same load is connected closer to the source.

Refou et al. (2015) state that an energy loss is the difference between the units of electricity purchased from the transmission utility and the units sold by customers.

Parmar (2013) asserted that the many causes of distribution losses include lengthy distribution lines, which increase resistance, inadequate size of conductors of distribution lines, and installation of distribution transformers away from load centres, which account for decreased voltage at the consumer's end. He further states that the low Power Factor of primary and secondary distribution systems, Load Factor and unbalanced 3-phase loads affect distribution losses.

For this study, the Electricity Company of Ghana’s network is an example. It must be noted that previous system loss assessment works done in 1992 by the Electricity Supply Board of Ireland (ESBI, 2000) by Power Planning Associates Limited (PPA) and by (Global Energy Consultant Engineers of India 2012) did not consider the effect/impact of various factors that causes losses make on the total distribution technical losses in Ghana. The technical loss value obtained for the low voltage networks was based on assumed loading levels, which may not reflect the real situation on the ground.

Though many loss reduction strategies based on some recommendations have been implemented, not much has been achieved. Therefore, the need to investigate how much each factor contributes to the total distribution of technical losses is evident. This work seeks to find the extent of each possible factor's contribution.

NETWORK DESCRIPTION

All 40 of the LV network used in this study could be found in the Kumasi Metropolis of the Ashanti Region of Ghana. Concerning the Utility, they are part of the LV network of the Electricity Company of Ghana, Ashanti Strategic Business Unit. The HV circuit feeding the area is an 11 kV overhead line with an 11m wooden pole structure. The transformers connected are of various sizes and constructional types: pole (PMT) or ground mounted (GMT). The ground-mounted one was once connected to the HV overhead line through AL XLPE cables of 185 mm^2 and 240 mm^2. The secondary side of the transformers is mainly connected to the LV network through distribution pillars (DP) ranging from 4-way to 8-way. The connections between the GMT and through the DP to the loads are made of 240mm^2 ALXLPE to 630mm^2 ALXLPE. The GMTs are rated from 315KVA and above, while the PMTs are rated from 200KVA and below.

The LV overhead lines are constructed on 9m wooden poles with either 50mm^2 or 120mm^2 bare aluminum conductors. They are vertically constructed, with the Red Phase Conductor 7.35m above the ground and the neutral conductor 6.45 m below.

The study area is predominantly residential, with few commercial activities. As a result, most of the loads are single-phase, with only a handful of three-phase loads. Table 1 gives a summary of the constructional components of all 40 LV networks.

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Table 1: Summary of Constructional Components

	Total connected load (KW)	No. of Circuits	No. of Poles	No. of Loads	Total Circuit Length (km)		Total connected load (KW)	No. of Circuits	No. of Poles	No. of Loads	Total Circuit Length (km)
circuit 1	187.5	3	80	54	3.14	**circuit 21**	468.9	3	100	219	4.06
circuit 2	562.5	4	71	87	3.36	**circuit 22**	545.5	3	64	74	2.70
circuit 3	592.5	6	81	60	3.56	**circuit 23**	448.9	2	36	52	1.75
circuit 4	417.5	3	59	50	2.56	**circuit 24**	177.2	2	30	31	2.33
circuit 5	755	4	86	100	4.15	**circuit 25**	184.6	2	38	43	3.42
circuit 6	765	4	73	99	3.74	**circuit 26**	430.4	3	36	55	1.22
circuit 7	317.5	4	68	74	3.03	**circuit 27**	539.3	3	41	54	1.63
circuit 8	162.5	3	35	40	1.27	**circuit 28**	512.9	4	45	97	1.88
circuit 9	317.5	3	41	36	1.63	**circuit 29**	175.6	2	40	43	1.66
circuit 10	282.5	4	56	45	2.33	**circuit 30**	107.5	2	30	23	1.20
circuit 11	420	5	89	82	3.53	**circuit 31**	419.9	4	86	89	3.64
circuit 12	637.5	4	91	95	4.35	**circuit 32**	106.6	2	25	36	1.18
circuit 13	882.5	4	170	155	8.34	**circuit 33**	271.7	2	75	191	2.91
circuit 14	705	5	161	119	6.72	**circuit 34**	268.2	2	52	148	1.55
circuit 15	862.5	5	176	152	7.51	**circuit 35**	289.5	3	40	166	1.55
circuit 16	1485	5	199	157	9.13	**circuit 36**	266.5	2	43	65	1.77
circuit 17	1487.5	6	201	219	9.71	**circuit 37**	518.5	2	44	121	2.25
circuit 18	148.5	2	53	34	2.09	**circuit 38**	518.5	2	65	177	2.25
circuit 19	614.1	2	26	29	1.18	**circuit 39**	613.2	3	107	270	3.71
circuit 20	329.2	2	45	38	1.82	**circuit 40**	613.2	3	102	270	4.07

METHODOLOGY

The research is designed as an experimental-quantitative study. All relevant information such as network structure, the length of LV lines, type of conductors, phases at which loads are connected, buses that the loads are connected, consumer peak consumption (KW), transformer capacities were collected form Electricity Company's network data base and some site confirmation and other resources, requirements, literature studies and other materials needed for the write-up were collected from journal, texts book and research papers.

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40 randomly selected LV networks in urban, rural and metropolitan areas were modelled on OpenDSS platform and steady state load flow studies were carried out. 14 predictors were then extracted as input to a regression analysis. The predictors were subjected to a correlation analysis to eliminate correlated predictors and hence produce the same or similar effect. Finally, a regression equation was formulated to express the impact of the non-correlated predictors on technical losses. formulate a regression equation that could be used to develop a loss reduction strategy for each

Extraction of Needed Variables for Regression Analysis

Factors relating to network configuration, electrical parameters, simulation results and calculated factors from the simulation results for all 40 networks were defined as follows:

1. Calculated Line losses (KW) (from simulation results)

   Active Losses in three-phase AC lines are given as:

   $$\Delta P = 3I^2R = 3(I_a^2 + I_P^2)R \tag{1}$$

   Where:

   R is the line resistance, I_a and I_p-values of the active and reactive components of the total line current I.

   Express the values of I_a and I_p in terms of power P and reactive power Q, and substituting, we get one of the primary expressions for electrical networks:

   $$\Delta P = 3I^2R = \frac{P^2+Q^2}{V^2}R = \frac{S^2}{V^2}R \tag{2}$$

   where S is the apparent power.

   This refers to the total active line losses from the simulation results and is given in KW.
2. Total connected load (KW) (from simulation input data). Considering the physical technical essence of expression (2), it is clear that active losses are dependent on connected active and reactive powers. It is the aggregated active load connected to the LV network
3. Source voltage (V) (from simulation results)

   Once again, looking at expression (2), it is evident that technical losses are inversely proportional to the voltage square. Therefore, even a slight increase in voltage leads to a significant reduction in power loss.

   This refers to the average of the three voltages measured at the secondary terminals of the distribution transformer.
4. Average Bus Voltage (V) (calculated from simulation results)

This is the average of all bus voltages in the network regardless of phase. This gives an idea of the magnitude of the load bus voltage of the equivalent source-line-load representation of the network, as in Figure 1.

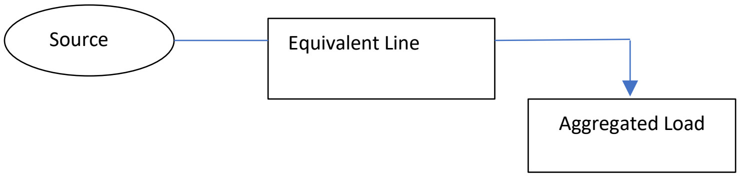

Figure 1: Equivalent Circuit

5. % Voltage Imbalance (calculated from simulation results)
   This defines the level of bus voltage imbalance across the network. It is expressed as:

$$\frac{(Maximum\ Deviation\ from\ Average)*100}{Average\ Voltage} = \%\ Voltage\ Imbalance \qquad (3)$$

6. Average Phase Current (KA) (calculated from simulation results)
   From expression (1), it is seen that the technical losses is proportional to the square of the current I
   This refers to the average value of the three phase-neutral currents measured at the output of the distribution transformer.
7. % Phase Current Imbalance (calculated from simulation results)
   Having established that technical losses are proportional to the square of the line current, it is obvious that when the current distribution is not even, some segment of the network with higher current flow will have relatively higher losses since the total losses are defined as the sum of the losses in individual segments. This can be proven as follows:
   $\Delta P = (I_1^2 + I_2^2 + I_3^2)R_{ph}$ (4)
   Assuming balanced loading of 2 amps and phase resistance of 5 ohms, the total losses will be
   $2\ amps, \Delta P = (2^2 + 2^2 + 2^2)5 = (4 + 4 + 4)5 = 60KW$ but if the loading is 1amp, 2apms and 3apms respectively the losses will be;
   $\Delta P = (1^2 + 2^2 + 3^2)5 = (1 + 4 + 9)5 = 70KW$
   This refers to the current imbalance of the three phase-neutral currents measured at the output of the distribution transformer and it is expressed as:

$$\frac{(Maximum\ Deviation\ from\ Average)*100}{Average\ Phase\ Current} = \%\ Phase\ Current\ Imbalance \qquad (5)$$

8. Average Phase Current Squared (KA^2) (calculated from simulation results)
   Any phase of a network with scattered loads can be reduced to a single load connected to a source through a line, as shown in Figure 1. The technical losses for the given equivalent circuit can be calculated as:
   $$\Delta P = I_{avg}^2 R_{avg} \tag{6}$$
   This represents the average of the square values of all line segments' current
9. Average line Resistance (Ohms/km) (calculated from simulation input data)
   It is the equivalent per km line resistance of the equivalent source-line-load circuit.
   This can be computed as follows:
   $$R_{avg} = \frac{\sum_{i=1}^{n} l_i R_i}{l_{total}}, \tag{7}$$
   $where\ l_i\ is\ the\ length\ of\ line\ segment\ and\ R_i\ is\ the$ Ohms/km Total Circuit Length (km)
   The cumulative length of all line segments of the LV network without reference to phases and computed as:
   $$l_{total} = \sum_{i=1}^{n} l_i\ and\ leads\ R = \frac{\rho l_{total}}{A} \tag{8}$$
   Therefore, the longer each line segment, the higher the line resistance since resistance is proportional to length. The same can be said for a higher number of segments.

10. Equivalent Load Distance (km) (calculated from simulation results and network configuration)
    This is the length of the line of the equivalent circuit as shown in Figure 1. It is expressed as:
    $$\text{Equivalent Load Distance,} \quad l_{leq} = \frac{\sum_{i=1}^{n}(P * L)}{\sum_{i=1}^{n} P} \tag{9}$$
    Having, $\Delta P = I^2 R = I^2 \left(\frac{\rho l_{leq}}{A}\right)$, the shorter the equivalent load distance the smaller the technical losses and the longer the equivalent load distance the higher the technical losses. This gives an idea of how far the aggregated load is from the source.
    The following expressions were used to determine the weighted distances (PL) of the loads from the source of supply.

$$\begin{bmatrix} Vertical\ Matrix\ of\ lengths \\ of\ Line\ Segment \end{bmatrix} \begin{bmatrix} Network\ Connectivity \\ Matrix \end{bmatrix} = \begin{bmatrix} Matrix\ of\ distance \\ of\ loads\ from\ Source \end{bmatrix}$$

$$\begin{bmatrix} Matrix\ of\ Weighted\ distance \\ of\ loads\ from\ source \end{bmatrix} = \begin{bmatrix} Vertical\ Matrix\ of\ loads \\ connected\ at\ each\ node \end{bmatrix} \begin{bmatrix} Matrix\ of\ distance \\ of\ loads\ from\ Source \end{bmatrix} \tag{10}$$

11. Average Load Power Factor (calculated from simulation results)
    This is the Average power factor of all the connected loads regardless of phase to which they are connected. It is given as:

$$pf_{avg} = \frac{\sum_{i=1}^{n} pf}{n} \text{ and } P = \sqrt{3}VIcos\varphi = \sqrt{3}VIpf_{avg} \tag{11}$$

Considering figure 1, and taking the aggregated load to have a power factor of pf_{avg}. Then the technical losses of the equivalent circuit will be proportional to the average power factor.

12. Product of Average Phase Current $(KA)^2$ and Average line Resistance (Ohms/km)
    This represents the I^2R per km length of the LV line.
13. Product of Average Phase Current (KA) and Average Load Power Factor
    This gives an idea of the LV line's voltage drop per km length.
14. Average Line Percentage loading. (calculated from simulation results)
    This is the average of the percentage loading of all segments of the LV network. It is expressed as:

$$\%\ loading_{line\ segment} = \frac{Actual\ load\ in\ line\ segment}{Rated\ Conductor\ Ampacity} \tag{12}$$

$$Average\ \%\ loading_{system} = \frac{\sum_{i=1}^{n} \%\ loading_{line\ segment}}{n} - \tag{13}$$

For any given segment of the network, the technical losses can be defined as:
$\Delta P = I^2R$ Therefore, for the same resistive value, if a lower current passes through the segment, it will result in a lower technical loss, and if the current value increases, the technical losses will also increase.

Simulation Input Data For Regression Analysis

Table 2 presents the proposed variables used in the regression process. It shows the variables obtained from the simulation of all 40 LV networks using the OpenDSS software.

Table 2. Regression input data

Circuit	losses (KW)	total connected load (KW)	Average source voltage (V)	Average Bus Voltage (V)	% Voltage Imbalance	Average Phase Current (KA)	% Phase Current Imbalance	Average Phase Current Squared (KA^2)	Average line Resistance (Ohms/km)	Total Circuit Length (km)	Equivalent Load Distance (km)	Average Load Power Factor	Line Average Percentage loading	I^2R	Icos ang
circuit 1	6.459	187.5	244.03	236.6	9.465	0.297	14.78	0.088	0.255	3.14	0.4422	0.896	9.466	0.023	0.266
circuit 2	24.13	562.5	253.69	236.6	13.9	0.894	2.122	0.799	0.228	3.001	0.3369	0.893	23.54	0.182	0.798
circuit 3	29.86	592.5	241.34	228.7	17.47	0.99	6.663	0.98	0.231	3.558	0.2571	0.887	20.87	0.227	0.878
circuit 4	31.73	417.5	244.46	223.3	19.83	0.707	9.126	0.499	0.245	2.562	0.3461	0.893	25.53	0.123	0.631
circuit 5	53.58	755	241.19	225.7	20.69	1.272	11.95	1.617	0.233	4.152	0.3541	0.893	26.41	0.376	1.135
circuit 6	54.72	765	241.08	223.7	16.47	1.291	9.198	1.666	0.225	3.74	0.349	0.892	29.62	0.376	1.151
circuit 7	21.16	317.5	244.07	237.9	9.877	0.504	15.42	0.255	0.249	3.028	0.3855	0.892	16.7	0.063	0.45
circuit 8	2.789	162.5	245.62	242	7.395	0.248	12.97	0.061	0.253	1.229	0.1975	0.898	9.377	0.016	0.223
circuit 9	21.21	317.5	244.46	232.9	11.91	0.514	4.778	0.264	0.254	1.629	0.3143	0.897	23.59	0.067	0.46
circuit 10	11.4	282.5	244.9	236.9	15.16	0.446	12.72	0.199	0.246	2.328	0.3471	0.896	15.95	0.049	0.4
circuit 11	15.63	420	245.03	236.2	9.196	0.667	14.02	0.445	0.245	3.528	0.3152	0.892	15.5	0.109	0.595
circuit 12	44.15	637.5	241.63	225.8	23.62	1.057	11.39	1.118	0.239	4.348	0.3748	0.893	22.35	0.267	0.944
circuit 13	90.17	882.5	249.14	220.9	35.09	1.443	2.574	2.082	0.253	8.342	0.5832	0.892	20.88	0.526	1.287
circuit 14	96.02	705	252.59	223.1	28.68	1.206	5.824	1.454	0.254	6.725	0.5953	0.894	25.52	0.37	1.078
circuit 15	117	862.5	247.24	213	42.01	1.509	8.287	2.277	0.256	7.513	0.512	0.85	23.78	0.582	1.283
circuit 16	240.3	1485	251.17	208	47.66	2.456	8.322	6.033	0.251	9.131	0.5949	0.893	36.36	1.512	2.194
circuit 17	200.3	1487.5	249.32	215.4	35.81	2.498	5.312	6.24	0.254	9.707	0.4991	0.892	30.62	1.587	2.229
circuit 18	14.97	148.5	254.47	238.5	22.71	0.24	11.77	0.057	0.255	2.089	0.3598	0.895	20.66	0.015	0.214
circuit 19	74.34	614.1	240.64	201.9	30.42	1.044	3.488	1.09	0.22	1.182	0.3283	0.903	66.84	0.239	0.943
circuit 20	18.13	329.2	244.87	220.6	25.97	0.561	5.418	0.314	0.235	1.818	0.2434	0.884	27.53	0.074	0.496
circuit 21	92.9	468.9	255.64	206.2	51.23	0.719	7.274	0.517	0.55	4.059	0.5194	0.908	33.47	0.284	0.653
circuit 22	39.66	545.5	243.88	228.7	24.74	0.895	14.64	0.801	0.239	2.703	0.3219	0.891	25.59	0.192	0.797
circuit 23	30.67	448.9	244.11	206.5	28.96	0.76	3.4	0.578	0.172	1.747	0.3702	0.889	36.52	0.099	0.676
circuit 24	8.262	177.2	241.92	235.3	11.84	0.287	25.25	0.083	0.545	2.328	0.2937	0.885	27.33	0.045	0.254
circuit 25	31.68	184.6	241.74	213.8	27.55	0.314	3.754	0.099	0.256	3.419	0.4539	0.896	29.85	0.025	0.281
circuit 26	16.28	430.4	241.66	233	13.55	0.677	8.932	0.459	0.251	1.216	0.1961	0.902	22.41	0.115	0.611
circuit 27	37.61	539.3	216.71	200.4	24	0.921	4.504	0.848	0.254	1.629	0.2899	0.893	34.11	0.215	0.823
circuit 28	43.01	512.9	251.91	235	21.92	0.821	5.907	0.675	0.5	1.884	0.1199	0.899	40.57	0.337	0.738
circuit 29	19.27	175.6	259.36	238.3	19.13	0.277	8.873	0.077	1.03	1.658	0.3428	0.895	34.38	0.079	0.248
circuit 30	10.73	107.5	245.08	227.5	18.68	0.18	22.71	0.032	1.047	1.203	0.1718	0.887	29.59	0.034	0.16
circuit 31	54.18	419.9	256.25	232.4	38.27	0.674	7.467	0.455	0.242	3.941	0.4166	0.893	35.27	0.11	0.602
circuit 32	6.337	106.6	245.17	234.6	10.44	0.173	5.313	0.03	1.056	1.177	0.0458	0.881	22.1	0.032	0.152
circuit 33	44.47	300.7	243.44	216.4	41.64	0.403	35.48	0.163	0.257	2.913	0.306	0.953	18.74	0.042	0.384
circuit 34	24.41	268.2	253.53	233.4	16.07	0.429	8.818	0.184	0.257	2.016	0.1943	0.887	21.52	0.047	0.381
circuit 35	26.06	289.5	252.05	233	26.22	0.478	3.895	0.228	0.313	1.554	0.3132	0.871	23.92	0.072	0.416
circuit 36	17.39	266.5	253.48	240.8	12.27	0.422	8.551	0.178	0.257	1.768	0.2101	0.876	20.87	0.046	0.37
circuit 37	21.35	518.5	252.4	200.5	23.15	0.639	26.78	0.408	0.251	1.621	0.2441	0.915	29.67	0.103	0.585
circuit 38	89.76	518.5	252.4	200.5	26.05	0.8	1.215	0.64	0.535	2.247	0.3213	0.915	42.06	0.343	0.732
circuit 39	88.76	613.2	254.66	221.7	22.61	0.934	6.607	0.872	0.256	3.711	0.3032	0.942	33.33	0.223	0.879
circuit 40	118.3	613.2	254.37	211.3	17.51	0.965	2.878	0.932	0.257	4.072	0.3713	0.942	35.33	0.239	0.909

RESULTS

Only seven of the fourteen predictors were not strongly correlated with Losses (kw). The results of the final correlation analysis are presented in Table 3.

Table 3: Final Correlation Results

Description	***losses (KW)***	***Average Bus Voltage (V)***	***% Voltage Imbalance***	***Average Phase Current (KA)***	***Average line Resistance (Ohms/km)***	***Equivalent Load Distance (km)***	***Average Load Power Factor***	***Line Average Percentage loading***
losses (KW)	1							
Average Bus Voltage (V)	-0.543	1						
% Voltage Imbalance	0.682	-0.637	1					
Average Phase Current (KA)	0.886	-0.453	0.535	1				
Average line Resistance (Ohms/km)	-0.175	0.156	-0.114	-0.348	1			
Equivalent Load Distance (km)	0.643	-0.348	0.609	0.588	-0.36	1		
Average Load Power Factor	0.133	-0.302	0.096	-0.063	-0.088	-0.032	1	
Line Average Percentage loading	0.394	-0.624	0.423	0.296	0.125	0.063	0.194	1

Final Regression Analysis

Although some variables were strongly correlated with others, it was necessary to regress them together to determine whether they would result in an accepted output. Table 4 represents the final regression analysis carried out on the original input data.

Because when there is no current flow or no load is connected to the circuit, there will be no technical losses; hence, the regression parameter 'constant' was set at zero, meaning no intercept will be part of the regression equation. The confidence level was also set at 95%

Table 4: Regression Results
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.964943
R Square	0.931115
Adjusted R Square	0.888287
Standard Error	20.41968
Observations	40

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	7	185989.5	26569.93	63.72249	5.50485E-17
Residual	33	13759.79	416.9632		
Total	40	199749.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Average Bus Voltage (V)	-0.22525	0.403308	-0.5585	0.580276	-1.04578	0.59529
% Voltage Imbalance	205.0515	120.639	1.699712	0.098594	-40.3903	450.4934
Average Phase Current (KA)	69.53549	8.517177	8.164147	2E-09	52.20716	86.86381

African Journal of Applied Research
Vol. 11, No. 2 (2025), pp.153-168
http://www.ajaronline.com
https://doi.org/10.26437/ajar.v11i2.995
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Peer reviewed: May 10, 2024
Revised: November 27, 2024
Published: April 2025

Average line Resistance (Ohms/km)	31.44336	16.8036	1.871227	0.070202	-2.74383	65.63054
Equivalent Load Distance (km)	53.63594	39.39399	1.361526	0.182572	-26.5117	133.7836
Average Load Power Factor	-71.5525	16.85818	-4.24438	0.000167	-105.851	-37.2543
Line Average Percentage loading	0.212186	0.454339	0.467022	0.643553	-0.71217	1.136545

Regression Equation

Using the following connotation as given in Table 5
Table 5. Connotation used for predictors

Predictor	**Connotation**
Average Bus Voltage (V)	X_1
% Voltage Imbalance	X_2
Average Phase Current (KA)	X_3
Average line Resistance (Ohms/km)	X_4
Equivalent Load Distance (km)	X_5
Average Load Power Factor	X_6
Line Average Percentage loading	X_7

The final regression equation could be expressed as:

$$
\begin{aligned}
KW\ Losses = {} & -0.22525X_1 + 205.0515X_2 + 69.53549X_3 + 31.44336X_4 + 53.63594X_5 \\
& - 71.5525X_6 + 0.212186X_7 + \varepsilon
\end{aligned}
$$

DISCUSSION

The model in Table 4 indicates that the final model has a linear relationship (correlation coefficient) of 0.96. The Adjusted R^2 value of 0.88 suggests that the various predictors have 88% of the value for all 40 observations located around the mean of the KW losses, this is an agreement withv Amyotte, and Ordonez, (2020) who argued that the 88% value for an electrical network is quite significant because several influencing factors, like wind speed, pollution level, components of the atmosphere, and temperature variations, among others, are not modelled.

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The Significance F value of 5.50485E-17 also presents a high level of statistical significance of the model.

Turning to the P-Values presented in the results, the predictors could be grouped into three categories, namely;

- High Statistical Significance
- Medium Statistical Significance
- Low Statistical Significance

The average Phase Current at a level of 2E-09, followed by the Average Load Power Factor of 0.000167, falls into the first category. This aligns with the finding of Essary (2011), which noted that considering both metrics together, it is clear that the system is operating with negligible real power demand and current draw, falling squarely into what is often designated as the first category.

The average line Resistance (Ohms/km) of the Statistical Significance level of 0.070202 and the % Voltage Imbalance of the Statistical Significance level of 0.098594 fall within the second category.

Predictors in the third category are the Equivalent Load Distance (km) of a Statistical Significance level of 0.182572, aligns with the finding of Singh, (2020) who observed that load distance often plays a secondary but contextually important role in predicting energy distribution efficiency and voltage drop across transmission lines especially in semi-urban or developing grid environments. Singh emphasised that distance is not always a dominant factor, but its effects become more pronounced when combined with system loading patterns and terrain-related transmission losses. Average Bus Voltage (V) of a Statistical Significance level of 0.580276 and Line Average Percentage loading of a Statistical Significance level of 0.643553

Regression Coefficients

The coefficients for each predictive variable tell us the average expected change in the response variable, assuming the other predictive variable remains constant. From the results presented in Table 4, the coefficient of Average Bus Voltage (V) of -0.22525 means a unit change will result in a 0.2525 unit change in the KW Loss value, to positive or negative. The sign of the coefficient means that if the value is appreciated by one unit, KW Losses will be reduced by 0.2525 units, concerning the decimal value of the units.

Similarly, the following are the effects of a unit change in the remaining predictors:

- % Voltage Imbalance=205.0515 to the decimal value of the units.
- Average Phase Current (KA) = 69.53549 to the decimal value of the units.

- Average line Resistance (Ohms/km) = 31.44336 concerning the decimal value of the units.
- Equivalent Load Distance (km) = 53.63594 to the decimal value of the units.
- Average Load Power Factor = -71.5525 to the decimal value of the units.
- Line Average Percentage loading = 0.212186 for the decimal value of the units.

Based on the results, this study suggests that an increase in the values of Average Bus Voltage (V) and Average Load Power Factor will decrease KW Losses. In contrast, an increase in all other predictors will increase KW Losses of the LV circuit. These results resonate with Siraj and Khan (2020), who identified similar predictors as contributors to technical losses, particularly in densely loaded or extended LV distribution systems. Their findings supported the idea that while system design constraints may make some factors unavoidable, their negative impact on efficiency must be addressed through planning and operational controls.

CONCLUSION

Factors like line resistance, circuit length, load power factor, and a transformer located far away from loads contribute to technical distribution losses. The question of how much each factor contributes to the total losses has not been addressed in existing literature. Forty LV circuits were modelled in OPENDSS SOFTWARE, and fourteen expected predictors were extracted from the simulation results. Correlation followed by regression analyses was carried out to determine the significant predictors and their coefficients. Based on statistically significant predictors, they could be categorised into three categories: Average Phase Current and Average Load Power Factor, which fall within the first category. Average line Resistance (Ohms/km) and % Voltage Imbalance fall within the second category. Predictors in the third category are the Equivalent Load Distance (km), Average Bus Voltage (V) and Line Average Percentage loading.

From the results presented in Table 4, the coefficient of Average Bus Voltage (V) of -0.22525 means a unit change will result in a 0.2525 unit change in the KW Loss value, to positive or negative. The sign of the coefficient indicates that if the value is appreciated by one unit, KW Losses will be reduced by 0.2525 units, concerning the decimal value of the units.

Similarly, the following are the effects of a unit change in the remaining predictors:
% Voltage Imbalance=205.0515 to the decimal value of the units, Average Phase Current (KA) = 69.53549 to the decimal value of the units, Average line Resistance (Ohms/km) = 31.44336 concerning the decimal value of the units, Equivalent Load Distance (km) = 53.63594 to the decimal value of the units, Average Load Power Factor = -71.5525 to the decimal value of the units and Line Average Percentage loading = 0.212186 for the decimal value of the units.

Based on the results, this study suggests that an increase in Average Bus Voltage (V) and Average Load Power Factor values will decrease KW Losses. In contrast, an increase in all other predictors will increase KW Losses of the LV circuit.

The findings of this work could be used in decision-making regarding the nature of the technical losses reduction strategy to be used for each LV network to achieve adequate performance.

Technical losses result in the unnecessary consumption of energy resources, which often include fossil fuels. Reducing these losses lessens the overall demand for power generation, leading to lower greenhouse gas emissions and reduced environmental impact. This supports broader sustainable development goals and helps meet national and global climate targets.

When power systems operate more efficiently and transparently, public confidence in utility providers increases. A clear strategy for tackling technical losses supported by data-driven insights demonstrates a commitment to good governance, accountability, and responsible public service. This can lead to stronger community cooperation, including in areas such as energy conservation and payment compliance.

FUTURE WORK

This paper formulates a regression equation based on a sample of forty low-voltage networks. The next part of this work is to use the results to develop a strategy to reduce the technical losses of circuit 21's worst case.

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