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EXPLORATIVE ANALYSIS OF 11KV FEEDER FAULTS IN NIGERIA ELECTRICITY DISTRIBUTION COMPANY NETWORK: CASE STUDY OF EKO ELECTRICITY DISTRIBUTION PLC

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Abstract—**Electricity is critical to socioeconomic development; however, reliability challenges persist in Nigeria's distribution networks despite sustained sector reforms since 1999. While generation and transmission have recorded modest improvements, the 11kV distribution level remains highly vulnerable to forced outages, significantly affecting service quality and revenue realization. This study presents a reliability assessment of 11kV feeders (fdrs) within Eko Electricity Distribution Plc (EKEDP) for a five-year (2020–2024) duration. Detailed outage log data were analyzed to identify dominant fault causes and quantify their technical and economic impacts using Energy Not Supplied (ENS) as a key performance indicator. The results indicate that cut jumpers, transient faults, RMU cable end box explosions, J&P and line fuse operations, tree interference, and mainline conductor failures are the primary contributors to 11kV fdr interruptions. The computed ENS values indicate substantial unserved energy, resulting in significant revenue losses over the study period. The findings emphasize the need for targeted infrastructure upgrades, improved protection coordination, and enhanced preventive maintenance strategies to strengthen fdr reliability and improve financial sustainability within Nigeria's 11kV distribution systems.**

Keywords— **11kV feeder, Forced Outage, Energy Not Supplied, Distribution Network, Fault Frequency.**

I. INTRODUCTION

Energy is a necessity for a country's socio-economic development [1-3], where every citizen has access to its supply. Many functions necessary for present-day living grind to a halt when the energy supply stops [4]. Moreso, electrical energy is a vital necessity across all domains of human activity. It is nearly universally recognized as a fundamental human requirement and has been highlighted as a crucial factor influencing the socio-economic progress of any nation. Electric energy has evolved into a foundational component of modern societal infrastructure, with most of our daily operations depending on the assumption of having easily accessible electric power [2]. However, as important as this product is, Nigeria has been grappling with significant challenges in its power supply sector [5], often characterized by epileptic or unreliable electricity supply. The country's power supply issues are a long-standing problem that has substantial social, economic, and political implications. Within the complex web of the electricity distribution system, 11kV feeders (fdrs) play a crucial role. These fdrs are responsible for transmitting electricity from substations to various distribution points, ensuring that power reaches consumers reliably. Also, the occurrence of faults in these fdrs can disrupt the flow of electricity, leading to service interruptions, economic losses, and inconvenience for consumers.

In Nigeria, Eko Electricity Distribution Plc (EKEDP) is a prominent player in the electricity distribution sector, serving a significant portion of Lagos State. Like many utilities in Nigeria and around the world, EKEDP grapples with the challenge of addressing faults in its 11kV fdrs to maintain a stable and resilient power supply. Understanding the nature, causes, frequency, and duration of 11kV fdr faults is essential for optimizing maintenance strategies, enhancing service reliability, and ensuring customer satisfaction.

II. CONCEPT AND REVIEW OF RELATED WORKS

From 1999 to date, significant investment has been made in the electricity sector [6]; however, the 11kV fdrs in EKEDP network still face specific challenges that can impact the reliability of electricity supply to its consumers and the overall performance of these fdrs. Along the chain of the electric power system, which includes generation, transmission, and distribution, the 11kV distribution system is the most problematic [7-10] because of frequent power outages resulting in high fdr frequency of tripping and high fault duration. For example, the authors of [11] analyzed five years of outage and downtime data of Idi-Araba 33/11kV Injection Substation (ISS) and showed that while the 33kV feeders (Akangba and Isolo) that are feeding the ISS maintained very high reliability and availability, the 11kV feeders (Babalola, LUTH, Idi-Araba, Daniyan) had moderate reliability, averaging 63.61%. The study concludes that although the system showed resilience, the 11kV fdrs need improved maintenance and monitoring to meet growing demand. Furthermore, when a fdr is unable to pick load due to being out on fault, it results in economic losses and decreased customer satisfaction. The lack of a comprehensive understanding of fault patterns, root causes, and their impact hinders the distribution company's ability to develop effective maintenance strategies and proactively address fdr faults. Consequently, there is an urgent need to conduct an in-depth explorative analysis to identify prominent root causes of 11kV fdr faults within a Distribution Network (DN), understand the spatial distribution of faults in a DN, understand the impact of implementation of predictive maintenance strategies, man power availability, equipment availability, material availability, mutual understanding and alignment between communities and distribution firms, on the average fault duration of 11kv fdrs.

This research investigated the frequency, causes, and patterns of faults in 11kV fdrs to enhance the reliability and performance of DN, using EKEDP as a case study. EKEDP is an electricity utility company that services the southern part of Lagos state and Agbara axis of Ogun State, Nigeria. It has about three hundred and fifty active 11kV fdrs that are fed from over fifty-four (54) ISS. The distribution company (EKEDP) is structured into three non-administrative divisions known as circles: East, Central, and West. Each circle is further divided into smaller operational units called Districts or Business Units, which Business Managers manage.

Several studies have been carried out on the distribution sector of the Nigerian electricity industry. For example, Eluozor et al. [12] analyzed the performance of transformers on Woji village 11kV DN, identified overloads, used ETAP (Electrical Transient Analyzer Program) for simulation, and recommended capacitor bank compensation and infrastructure upgrades to improve reliability. In 2010, Adegboye [13] analyzed outages in Zaria Town's distribution system in Kaduna State, Nigeria, covering both 11 kV and 33 kV fdrs. For the 11 kV category, the study focused on five specific fdrs, collecting data for approximately one year (April 2003 to April 2004) and recording outage occurrences, their types, frequencies, and durations. From the results obtained, recommendations were proposed.

Akanni et al. [14] analyzed empirical data on natural electrical faults in the DNs of Lagos State, Nigeria. Network and fault information for all DN fdrs in the state were sourced from system records. The data were categorized under the two distribution companies (Discos): EKEDP and Ikeja Electricity Distribution Company (IKEDC). The data spans four years (2017-2020) for IKEDC and three years (2016, 2019, and 2020) for EKEDP. Based on the results, they established their findings and provided recommendations. Akanni et al. [14] also analyzed the causes of outages, their costs, energy losses, and the durations of outages experienced by electricity consumers in the distribution systems of Lagos State. They then proffered recommendations to minimize outages and their impacts.

In this research, a more in-depth analysis was conducted on fault records of EKEDP 11kV fdrs alone to gain insight into the main fault causes for high frequency of tripping, fault durations, and offer practical solutions to mitigate these fault causes from occurring. Moreso, the huge monthly monetary loss and energy loss established by Akanni et al. [14] justifies an urgent need to analyze the spatial distribution of 11kV faults and determine the main fdrs with high frequency of tripping rate and the main fault causes of the tripping, this would enable the management of EKEDP to be able to identify the major hotspot areas where maintenance efforts and infrastructure investments should be focused on to achieve fdr reliability, efficiency and customer satisfaction. Since Akanni et al. [14] also recommended that faults should be cleared on time to minimize outage duration, this justifies the need to analyze the fault record to identify the causes of the high fault duration in EKEDP 11kV fdrs, investigate and identify possible factors that impact the fault duration, and proffer practical recommendations.

III. METHODOLOGY

Five (5) years (2020-2024) of data on fault interruptions of 11kV fdrs within EKEDP was collected from its Power Systems Control (PSC) department, with due approval from the company's Managing Director and Chief Executive Officer. The acquired data was then analyzed using Python programming language, and Jupyter Notebook was the development platform. The process flow for this research method is shown in Fig. 1.

Python Modules such as NumPy, Pandas, operating system, Matplotlib.pyplot, process, Timedelta, and seaborn, among others, were imported. The Data was then uploaded into the development platform, the five (5) different years of data (in Excel format) were merged and named as MergedData. During the data preprocessing stage, it was observed that several columns in the dataset were not relevant to the objectives of the study and were therefore removed. Additionally, entries in the "Reason" column were standardized by converting them to proper case, as variations in word casing caused identical entries to be treated as distinct categories. Rows with the absence of vital information were also deleted. After which, the number of columns was thus reduced from forty-three (43) to fourteen (14) with a total row of fifty-two thousand, five hundred and thirty- two (52,532). The fourteen columns are s/n (serial number), circle, district, Injection substation, month, day, 11kV fdr, tripping indication, time occurred, time cleared, load lost (MW), Duration, Reasons, and year.

Mental Modeler software was used to design a model representing components that influence average fault duration for breaker faults and cable vandalism in the 11kV fdr network. The relationships between these components were defined as cause-and-effect connections. The interdependency

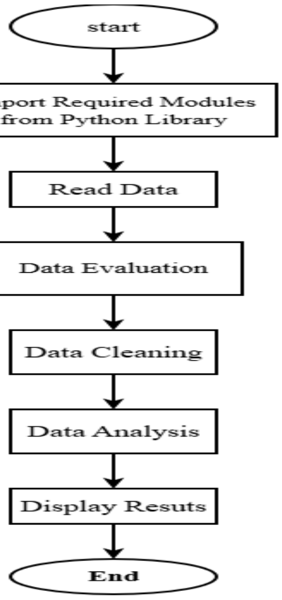

Fig. 1. Process Chart

mapping of the components was derived based on expert knowledge and group discussion amongst experts. The weights given to the components were assigned based on the majority vote amongst an 8-member expert team. This was done to ensure that the model being designed is as close as possible to real-world observations. Also, the positive or negative interdependency between the components was determined based on their expert judgement. Positive interdependencies mean that an increase in one component would lead to an increase in the other component, and a decrease in one component would lead to a decrease in another component. Negative interdependencies mean that a decrease in one component would lead to an increase in another component, and an increase in one component would lead to a decrease in another component (Fig. 2). The model was validated by comparing its predictions with real-world observations, and adjustments were made to improve the model's accuracy.

Energy Not Supplied (ENS): In this study, ENS was used as an indicator of outage severity and revenue impact. It quantifies the total energy that could not be delivered due to fdr fault (forced outage). Unlike simple fault frequency or cumulative outage duration, ENS incorporates both the magnitude of load loss and the duration of each interruption, thus providing a more comprehensive reliability metric. For each interruption event i, ENS was thus calculated as shown in Eq. 1.

$$ENS = \sum_{i=1}^{n}(p_i \times t_i) \quad (1)$$

where p_i is load lost during the interruption i in MW, t_i is the duration of interruption i in hours, and n is the total number of interruption events.

To estimate the potential revenue impact, ENS was then monetized using the applicable tariff structure as shown in Eq. 2.

Revenue loss = ENS x 1000 x Average Tariff (2)

where the average tariff for Nigeria is banded. For Band A fdrs, it is 209.5 naira for a kWh; Band B is between 61 and 64.07 naira; Band C is between 48.53 and 52.05 naira; while Band D and E are between 32.48 and 43.27 naira and between 32.44 and 43.27 naira, respectively, for a kWh [15]. For this research, the fdrs considered fell into Band A and Band C; thus, 209.5 naira was used while calculating revenue loss for Band A, and 50 naira was applied for Band C. The 1000 that was used as a multiplying factor in Eq. 2 is to convert the ENS from MWh to kWh.

IV. RESULTS AND DISCUSSION

Results presented in Table 1 show that, from 2020 to 2024, the major reason for faults in EKEDP 11kV DN was jumper cut, with an occurrence of 10,582, load loss of 17,462.07MW, customer outage duration of 157,499 Hrs., 23min, and 10 secs, with an average duration of 14 Hrs., 53min, and 1 sec. The second reason for forced outage was transient faults. Transient faults are temporary disruptions in the electrical system that typically resolve themselves without requiring extensive intervention. For the period under consideration, it occurred 8,197 times with a total load loss of 17,845.99MW, total duration of 79,529 Hrs., 40 mins, and an average duration of 9 Hrs., 42 mins, 4 secs. Other top causes for forced outage include J&P fuse drop, blown line fuse, cable end box explosion from Ring Mains Units (RMU), cut overhead mainline, or mainlines detaching from insulators, trees fouling overhead lines, punctured cable and termination failures, shattered insulators (pots and disc insulators), straight through joint failures, among others (Table 1). The first ten (10) reasons are shown in Fig. 3 using a bar chart.

From Table 2, the top twenty fdrs with the highest tripping frequency were deduced. Ogombo 11kV fdr was at the top of the table, with a tripping frequency of 880, a total load loss of 2,588.82MW, a total duration of 9,477 Hrs., 6 mins, and an average duration of 10 Hrs., 46 mins, 10 secs. Furthermore, Moore Road 11kV fdr tripped 711 times within the period under consideration, resulting in a total load loss of 1,631.47MW, a total duration of 6,195 Hrs., 19 mins, and an average duration of 8 Hrs., 42 mins, 49 secs. Other fdrs include Spg, Langbasa, Adeola Hopewell, Ajiran, Addo Road, Otto Awori, State House, Estate (Ajah), Mulliner, Ajiwe 11kV fdrs, among others.

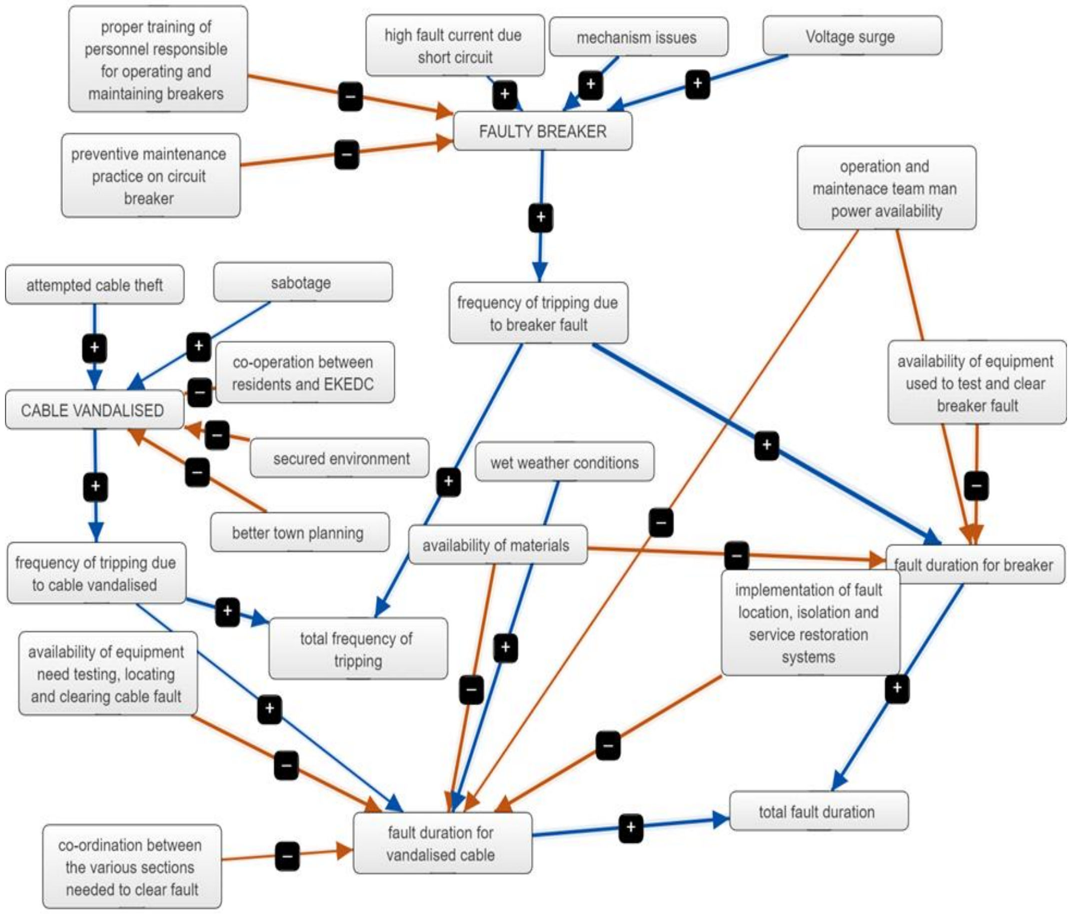

Fig. 2: Fuzzy cognitive mapping for causative factors with the highest duration in EKEDP 11Kv fdr network.

Table 1: Reasons for Fault, Frequency, Load Lost, Duration, and Average Duration

s/n	Reasons	Total fault count	Total duration	Total load lost MW	Avg duration
1	Jumper Cut	10582	157499:23:10	17462.07	14:53:01
2	Transient Fault	8197	79529:40:00	17845.99	09:42:08
3	J&P Fuse / Line Fuse Dropped Due To LV Fault	7124	91894:56:00	12309.51	12:54:04
4	Cable End Box Explosion at RMU	5079	58422:05:00	6429.868056	11:30:09
5	Mainline Cut, Loose, External Object or Detached from Insulator	4488	71886:11:35	7610.31	16:01:28
6	Tree Touching Line	3349	48718:50:59	5536.99	14:32:50
7	Isolation (Suspected Cable or Line Fault / Further Patrol)	2526	31070:35:00	3167.43	12:18:01
8	Cable Punctured / Termination	2340	55158:28:00	3090.71	23:34:19
9	Shattered Pot / Disc	1600	28066:45:00	2463.54	17:32:30

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	Insulator				
10	Cable Joint Failure	1122	40681:25:00	1197.18	36:15:28
11	Equipment Failure (Switchgear / Transformer)	793	23964:36:00	622.12	30:13:12
12	Weather Condition	742	3925:48:00	1399.93	05:17:27
13	Broken Cross Arm	539	8983:35:00	968.13	16:40:01
14	Bird / Animal Bridged the Line	507	5351:19:00	974.03	10:33:17
15	Emergency / Fire Outbreak	492	5352:14:00	1089.94	10:52:42
16	Broken / Fallen Pole	344	9409:24:00	553.51	27:21:10
17	Overloading	286	1302:31:00	1271.9	04:33:15
18	Moisture in Panel / Cable Termination	165	4208:47:00	116.46	25:30:28
19	Lightning Arrester Bad	145	2414:17:56	232.9	16:39:01
20	Relay Issue / Coordination	132	2688:16:00	118.93	20:21:56
21	RMU Faulty	117	2027:46:00	109.96	17:19:52
22	Cable Vandalized	109	3753:42:00	93.91	34:26:15
23	LV Fault	103	1210:02:00	192.5	11:44:52
24	Cable End Box Explosion at Feeder Panel	84	996:16:00	88.16	11:51:37
25	Accident / Vehicle / Electrocution / Human Error	53	978:38:00	80.21	18:27:53
26	Inter - Tripped	36	140:17:00	53.1	03:53:48

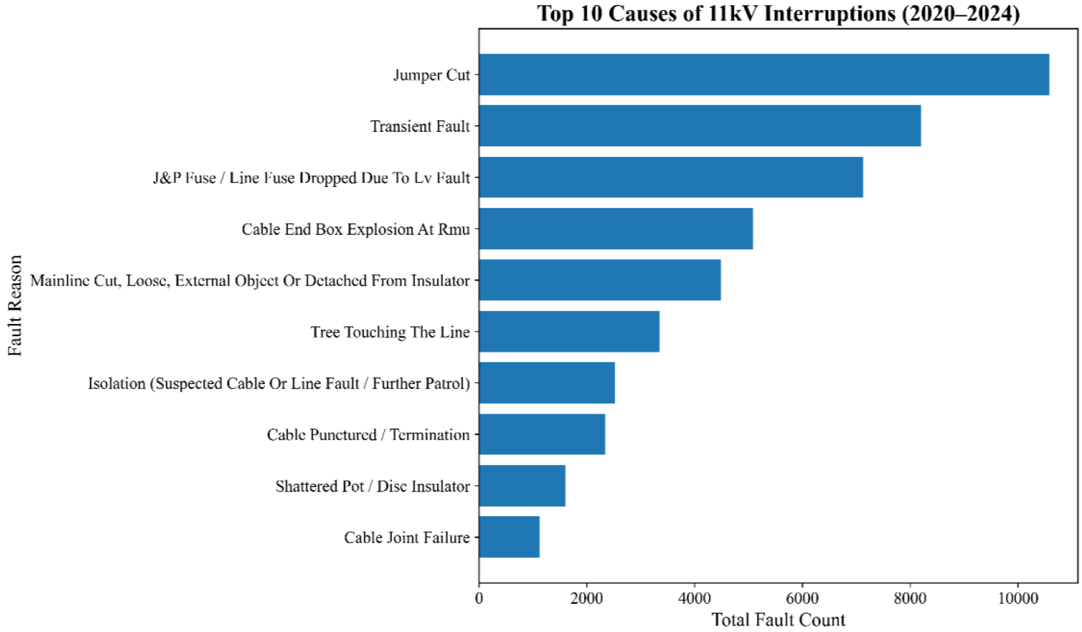

Fig. 3: Bar Chart of Top Ten Causes of 11kV faults.

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Table 2: Topmost Frequent Tripping 11kV fdrs in EKEDP Network

s/n	11kv fdr	No of trippings	Total load lost MW	Total duration	Avg duration
1	Ogombo	880	2588.82	9477:06:00	10:46:10
2	Moore Road	711	1631.47	6195:19:00	08:42:49
3	Spg	645	1445.26	6961:06:00	10:47:33
4	Langbasa	562	2018.23	6061:58:10	10:47:11
5	Adeola Hopewell	514	809.05	5042:39:00	09:48:38
6	Ajiran	502	1487.55	4267:37:00	08:30:04
7	Addo Road	500	1677.07	4515:37:00	09:01:52
8	Otto Awori	486	1309.7	7430:32:00	15:17:21
9	State House	476	787.57	4631:41:00	09:43:50
10	Estate (Ajah)	470	1623.06	3236:46:00	06:53:12
11	Mulliner	463	542.1	5105:00:00	11:01:33
12	Ajiwe	450	1228.36	4272:02:00	09:30:52
13	Shaw Road	442	1069.34	3702:04:00	08:22:33
14	Annex	424	808.39	3341:23:00	07:52:50
15	Osapa	409	483.08	3796:39:00	09:16:58
16	Etim Inyang	408	637.67	3253:35:00	07:58:28
17	Opic	401	793.8	6563:16:00	16:22:02
18	Ijanikin	396	1158.81	7785:51:00	19:39:40
19	Oba	392	809.13	6428:35:35	16:23:58
20	Fowler Local	389	622.12	4094:33:00	10:31:33

Table 3 shows the top five reasons for forced outage on Ogombo 11kV fdr. Ogombo fdr is an overhead network, and it can be observed that the main reason for its fault is Transient fault with a frequency of 279, a load loss of 1,071.6MW, a total duration of 1,629 Hrs., 37 mins, average duration of 5 Hrs., 50mins, 27 secs, and an ENS of 5,916.917MWhr (Eq. 1). Hence, the total revenue lost (Band C) is 295,845,850 naira (Eq. 2). The second major cause for forced outage on Ogombo 11kV fdr is jumper cut. It occurred 124 times with a total load loss of 306.71MW, duration of 1,858 Hrs., 51 min, an average duration of 14 Hrs., 59 min, 27 secs with ENS of 4,318.085MWhr (Eq. 1). Hence, the amount lost in Naira is 215,904,250 (Eq. 2). Other main causes of faults are J&P fuse rupture, Line fuse rupture, and mainline cut, among others (Table 3 and Fig. 4).

The second fdr with high-tripping frequency is Moore Road 11kV fdr. It is a fdr comprising an underground and overhead network; the major reason for fault is cable end box explosion from RMU. It occurred 265 times with a load loss of 642.84MW, a duration of 2,388 Hrs., 2 mins, an average duration of 9 Hrs. 41 secs and an ENS of 5509.098MWh (Eq. 1). Since it is a band A fdr, the cost of a kWh is 209.5 Naira, which translates to a revenue loss of 1,154,156,031 Naira (Eq. 2) (Table 4 and Fig. 5). The second top reason for forced outage on Moore Road 11kV fdr is due to trees fouling the overhead portion of the line. It occurred 108 times within the period under consideration, with a total load loss of 258.8MW. It has a total duration of 948 Hrs. 50 mins, an average duration of 8 Hrs., 47 mins, 8 secs, with an ENS of 2338.49MWh, making the financial loss to be 489,913,655.00 naira. Other reasons for fault are jumper cut, isolation made due to suspected cable faults that require further patrol, and J&P fuse drop or ruptured line fuse.

The third fdr with the highest tripping rate is Spg 11kV fdr. Its highest reason for fault is transient faults with a tripping frequency of 169, total load loss of 430.01MW, total duration of 1107 Hrs., 22 mins, an average duration of 6 Hrs., 33 mins, 9 secs with an ENS of 3039 (Eq. 1), which translates to a financial loss (Band A) of 636,670,500 Naira (Eq. 2) for a Band A fdr.. The second reason for fault on Spg is ruptured J&P fuse or line fuse. Its tripping frequency is 149; it has a total load loss of 320.7 MW, total duration of 1935 Hrs. 50 mins, an average duration of 12 Hrs., 59 mins, 32 secs, and an ENS of 4248.098. Therefore, the total cost for ENS is 889, 976,531 Naira (Eq. 2). Other top reasons for faults include jumper cut, isolation due to suspected cable fault, and tree fouling the line (Table 5, Fig. 6).

The fourth fdr with the highest tripping rate is Langbasa 11kV fdr. Its major reason for tripping is transient fault, which occurred 152 times within the period considered. The total load lost was 691,52 MW, the duration was 957 Hrs, 6 mins, and the average duration was 6 Hrs, 17 mins, 48 secs, and an

ENS of 4165.669MWh (Eq. 1). It then translates into a financial loss of 208,283,450 Naira. The second reason for tripping on Langbasa 11kV fdr is jumper cut. Its tripping frequency is 108, total load loss of 321.9 MW, total and average duration of 1351rs., 9 min, 10 secs, and 12 Hrs., 30 mins and 38 secs respectively with an ENS of 4,067.81MWhr. Hence, the financial loss is 203,240,500 Naira. Other top reasons for tripping on Langbasa 11kV fdr are ruptured J&P fuses, ruptured line fuses, cut overhead lines, or the overhead line detached from insulators, tree fouling the line, among others (Table 6 and Fig. 7).

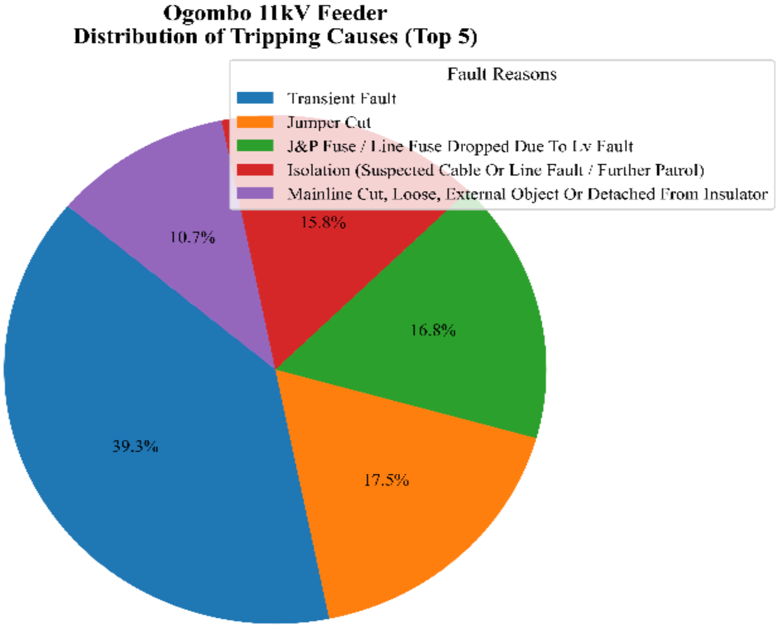

Fig. 4: Pie Chart of the Major Reasons for Faults on Ogombo 11kV Fdr

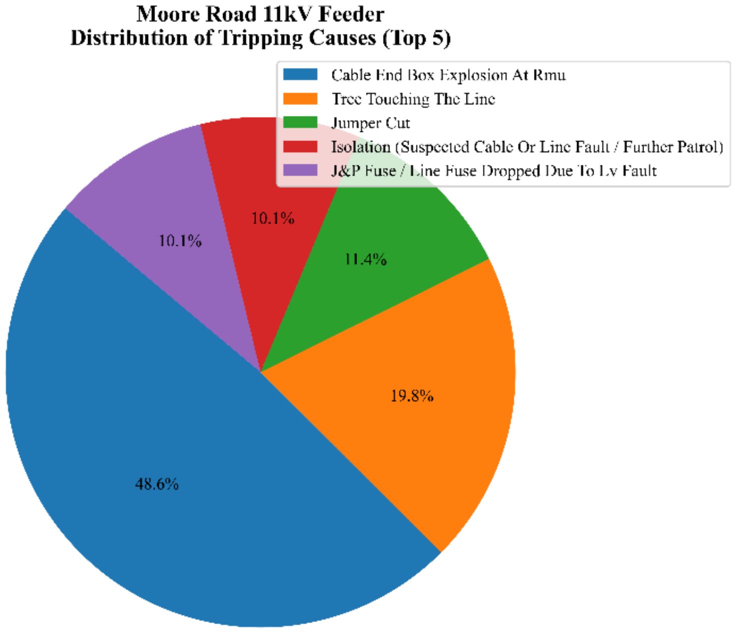

Fig. 5: Pie Chart of the Major Reasons of Fault on Moore Road 11kV Fdr

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Table 3: Top Five Reasons of Fault on Ogombo 11kV Fdr, Frequency, Duration, and Energy

s/n	Reasons	Frequency of Tripping	Total load lost MW	Total duration	Avg duration	ENS MWhr
1	Transient Fault	279	1071.6	1629:37:00	05:50:27	5916.917
2	Jumper Cut	124	306.71	1858:51:00	14:59:27	4318.085
3	J&P Fuse / Line Fuse Dropped Due To LV Fault	119	314.6	1562:43:00	13:07:55	3867.777
4	Isolation (Suspected Cable or Line Fault / Further Patrol)	112	279.91	1471:12:00	13:08:09	3586.248
5	Mainline Cut, Loose, External Object or Detached from Insulator	76	170.1	979:11:00	12:53:02	1864.048

Table 4: Top Five Reasons of Fault on Moore Rd 11kV Fdr, Frequency, Duration, and Energy

s/n	Reasons	Frequency of tripping	Total load lost (MW)	Total duration	Avg duration	Total MWh
1	Cable End Box Explosion at RMU	265	642.84	2388:02:00	09:00:41	5509.098
2	Tree Touching the Line	108	258.8	948:50:00	08:47:08	2338.49
3	Jumper Cut	62	136.1	521:57:00	08:25:07	1104.645
4	Isolation (Suspected Cable or Line Fault / Further Patrol)	55	108.41	486:42:00	08:50:57	948.4927
5	J&P Fuse / Line Fuse Dropped Due To LV Fault	55	132.2	362:21:00	06:35:17	835.8217

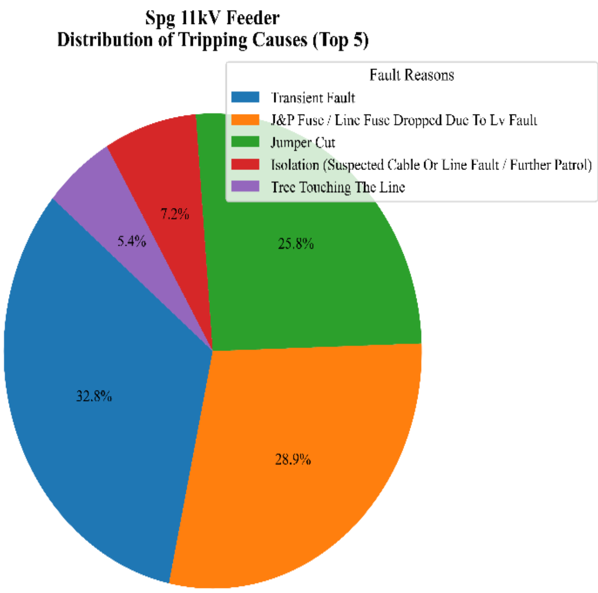

Fig. 6: Pie Chart of the Major Reasons of Fault on Spg 11kV Fdr.

The fifth fdr with the highest tripping rate was Adeola Hopewell. It is partly underground and partly overhead. Its major reason for tripping is explosion from RMU cable end box, which occurred 168 times with a load loss of 267.21 MW, a duration of 1669 Hrs., 28 secs, an average duration of 9 Hrs., 56 mins, 14 secs, and an ENS of 2382.106 MWh. Thus, translating into a financial loss of 499,051,207 naira. The second reason for tripping was transient fault, which occurred 76 times, with a load loss of 147.21 MW, within a time duration of 392 Hrs., 44mins, an average duration of 5 Hrs., 10mins, 3secs, and an ENS of 666.2302 MWh. The financial loss was 139,575,226.9 naira. Other top reasons for faults on Adeola Hopewell are ruptured J&P and line fuses, isolation made due to suspected cable fault, and jumper cut (Table 7 and Fig. 8).

Table 5: Top Five Reasons of Fault on Spg 11kV Fdr, Frequency, Duration, and Energy

s/n	Reasons	Frequency of tripping	Total load lost (MW)	total duration	Avg duration	ENS MWh
1	Transient Fault	169	430.01	1107:22:00	06:33:09	3039
2	J&P Fuse / Line Fuse Dropped Due To LV Fault	149	320.7	1935:50:00	12:59:32	4248.098
3	Jumper Cut	133	266.22	1662:47:00	12:30:08	3345.7
4	Isolation (Suspected Cable or Line Fault / Further Patrol)	37	71.9	292:59:00	07:55:06	514.645
5	Tree Touching the Line	28	68.7	360:57:00	12:53:28	932.9017

Table 6: Top Five Reasons of Fault on Langbasa 11kV Fdr, frequency, Duration, and Energy

s/n	Reasons	Frequency of tripping	Total load lost (MW)	Total duration	Avg duration	ENS MWh
1	Transient Fault	152	691.52	957:06:00	06:17:48	4165.669
2	Jumper Cut	108	321.9	1351:09:10	12:30:38	4067.81
3	J&P Fuse / Line Fuse Dropped Due To LV Fault	64	211.1	798:42:00	12:28:47	2561.285
4	Mainline Cut, Loose, External Object or Detached from Insulator	40	131.8	470:25:00	11:45:38	1514.732
5	Tree Touching the Line	40	129.5	506:04:00	12:39:06	1660.053

Table 7: Top Five Reasons for Fault on Adeola Hopewell 11kV Fdr, Frequency, Duration, and Energy

s/n	Reasons	Frequency of tripping	Total load lost (MW)	Total duration	Avg duration	ENS MWh
1	Cable End Box Explosion at RMU	168	267.21	1669:28:00	09:56:14	2382.106
2	Transient Fault	76	147.21	392:44:00	05:10:03	666.2302
3	J&P Fuse / Line Fuse Dropped Due to LV Fault	65	92.2	741:36:00	11:24:33	1011.347
4	Isolation (Suspected Cable or Line Fault / Further Patrol)	49	60.01	449:22:00	09:10:15	496.2992
5	Jumper Cut	47	60.81	576:35:00	12:16:04	664.367

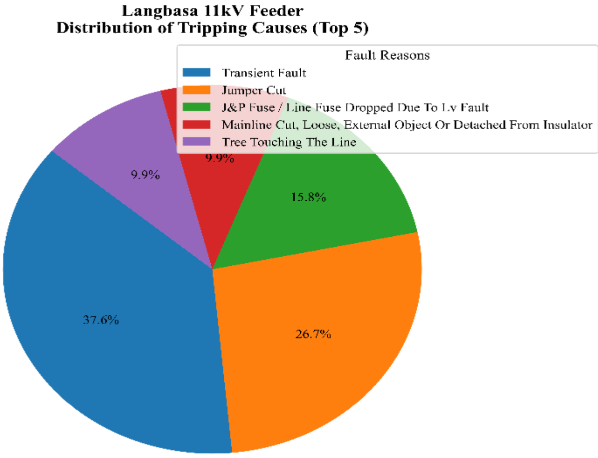

Fig. 7: Pie Chart of the Major Reasons of Fault on Langbasa 11kV Fdr

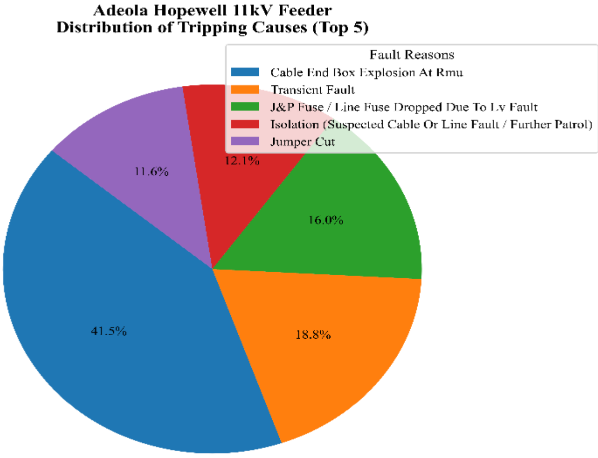

Fig. 8: Pie Chart of the Major Reasons of Fault on Adeola Hopewell 11kV Fdr

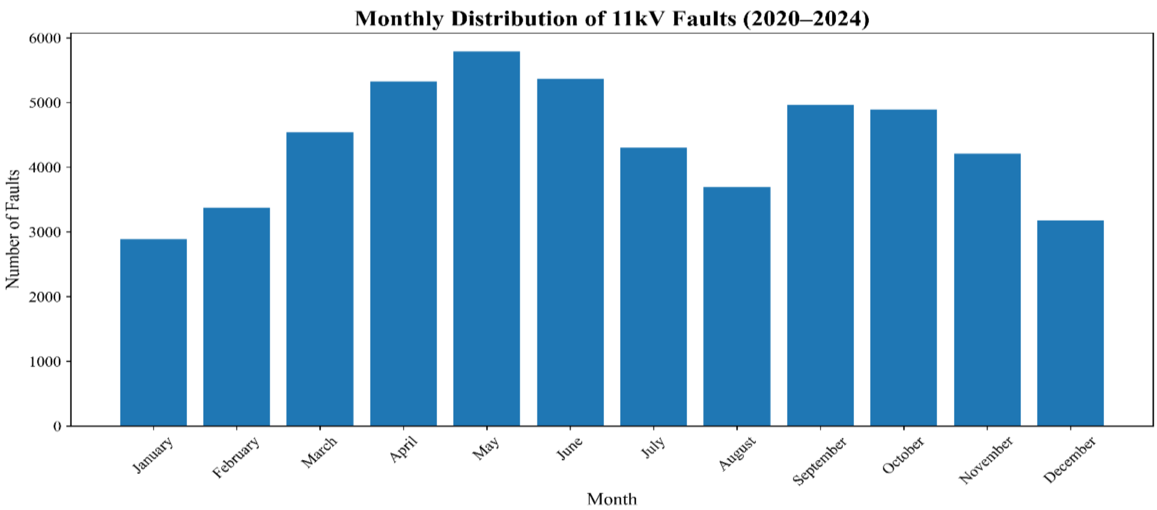

Fig. 9: Pie Chart of Frequency of Fault According to Months

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At this stage, it became necessary to examine the periods of the year during which tripping occurs more frequently (Table 8 and Fig. 9). It was observed that May (5,787), June (5,371), and April (5,328) had the highest tripping rates. The month with the least occurrence of fault is January, i.e., 2,890 times. Other months and their fault frequency are February (3,371), March (4542), July (4301), August (3695), September (4964), October (4895), November (4206), and December (3182). Table 10 shows the five (5) major reasons for forced outage, for May within the years under consideration. Observation of the table shows that Jumper cut was the main reason, with an occurrence of 1,185 times, a load loss of 1933.4, within a duration of 19,173 Hrs., 38 mins, an average duration of 16 Hrs., 10mins, 10 secs, and an ENS of 30,789.32 MWh. The next reason was transient fault that had an occurrence of 863, load loss of 1733.62MW, total duration of 7703 Hrs., 21 mins, an average duration of 8 Hrs., 55 min, 34 secs, and an ENS of 12474.62MWh. Other main reasons for faults during May were ruptured J&P fuses and line fuses, cable end box explosion from RMU, and cut 11kV mainline conductors (Table 9 and Fig. 10).

Table 8: Count of Faults According to Months of the Year

month	**Fault count**
January	2890
February	3371
March	4542
April	5328
May	5787
June	5371
July	4301
August	3695
September	4964

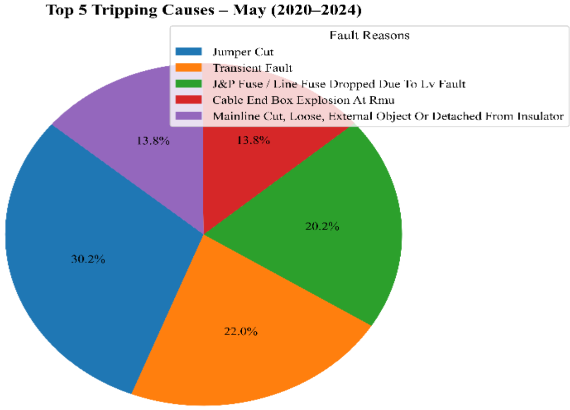

Fig. 10: Top 5 reasons for Tripping in May

Table 9: Five Main Reasons of Fault for May and their effect

s/n	**Reasons**	**Frequency of tripping**	**Total load lost MW**	**Total ENS MWh**	**Total duration**	**Avg duration**
1	Jumper Cut	1185	1933.4	30789.32	19173:38:00	16:10:49
2	Transient Fault	863	1733.62	12474.62	7703:21:00	08:55:34
3	J&P Fuse / Line Fuse Dropped Due to LV Fault	793	1372.25	18683.85	10925:32:00	13:46:39
4	Cable End Box Explosion at RMU	543	741.83	7333.662	5856:46:00	10:47:09
5	Mainline Cut, Loose, External Object or Detached from Insulator	542	935.32	15506.48	9531:47:00	17:35:11

From Table 1, it was identified that cable joint failure is the reason with the highest average fault duration of 36 Hrs., 15 mins, 28 secs, the total load loss was 1197.18MW, and its total duration was 40681 Hrs., 25 mins for a fault frequency of 1122. This must be because the cables are underground, and specialized equipment is required to locate the faulty point. Table 1 also lists vandalized cable as the fault cause, with the second-highest average fault duration of 34 Hrs., 26 mins, 15 secs, a total duration of 3753 Hrs., 42 Mins, load loss of 93.91MW, and a fault count of 109. The prolonged fault-clearing duration is likely due to administrative issues, such as filing a police report and informing affected communities. The reason for the fault with the third-highest average duration was equipment failure (switchgear/Transformer). This fault is basically due to 11kV breaker fault. It occurred 793 times during the period under consideration, with a load loss of 622.12MW, a total duration of 23,964 Hrs., 36 mins, and an average duration of 30 Hrs., 13 mins, 12 secs (Table 1).

Applying Mental Modeler, the research included modeling real-life situations of these conditions and actions that should be taken to improve their effects.

As seen in Fig. 11, an increase in the occurrence of cable theft and sabotage due to malicious intent would result in an increase of cable vandalized fault (0.48 units) in the system, increase in frequency of tripping due to cable vandalism (0.45 units), increase in total frequency of tripping within the system (0.22 units), increase in fault duration for cable vandalized (0.12 units) and increase in total fault duration in the system (0.06 units).

From Fig. 12, when there is better co-operation and mutual understanding between community members and the electricity utility company to ensure better community surveillance, also installation of CCTV camera in strategic places in partnership with either government agencies and/or private organization for more secured environment and better town planning to ensure that underground cables are well trenched and not easily prone to vandalism, it would result to decrease in cable vandalized fault in the system (-0.85 units), decrease in frequency of tripping due to cable vandalism (-0.69 units), decrease in total frequency of tripping within the system (-0.33 units), decrease in fault duration for cable vandalized (-0.18 units), and decrease in total fault duration in the system (-0.09 units).

Overall, improving cooperation between community members and EkEDP can lead to a more proactive approach to preventing cable vandalism and a faster response to faults when they do occur. It can help reduce fault duration, minimize service disruptions, and improve the reliability of the electrical supply in the area.

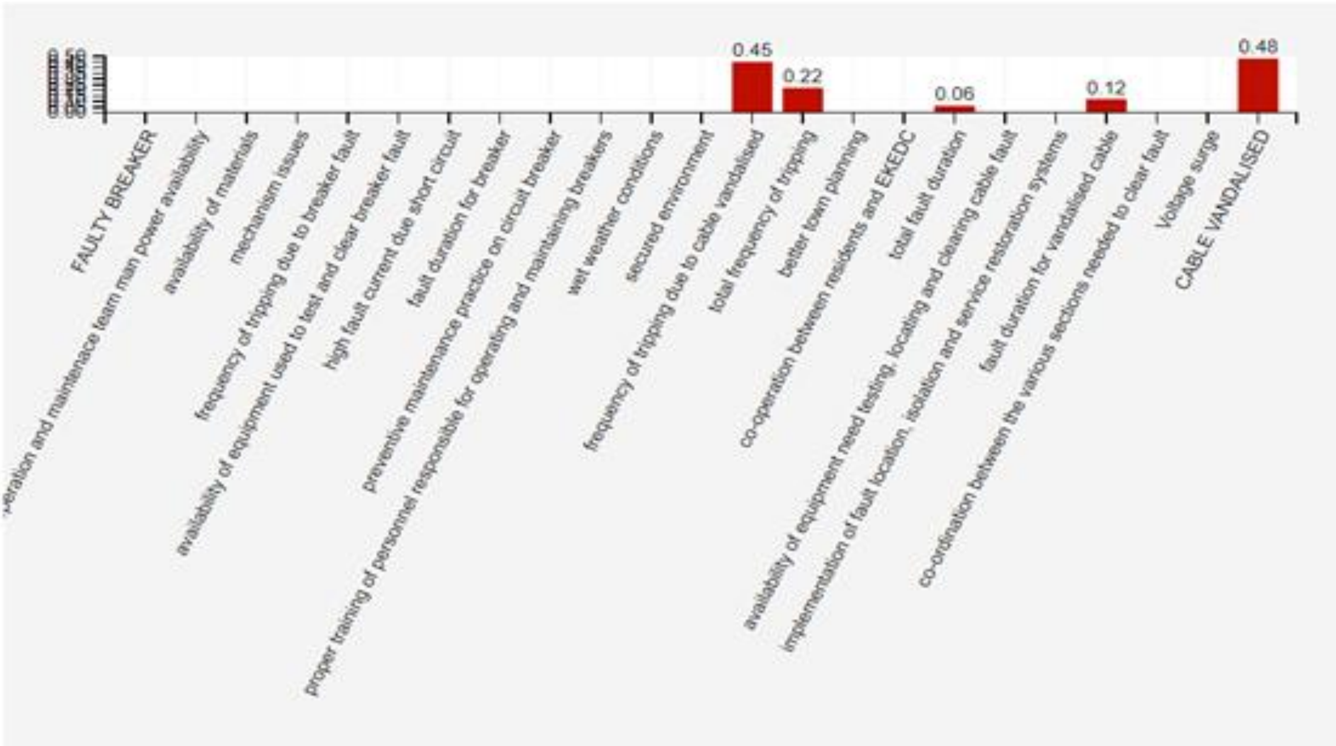

Fig. 11: Bar chart showing the impact of cable theft on the system

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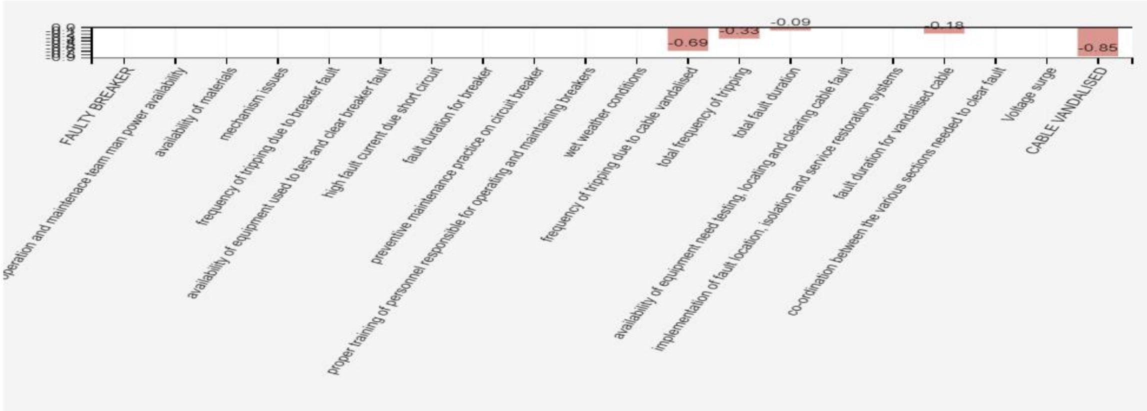

Fig. 12: Bar chart showing the impact of better town planning, co-operation between communities and EKEDC, and a secure environment on the system.

From Fig. 13 an increase in short circuit, breaker mechanism issues, and voltage surge would lead to an increase in breaker faults in the system (0.73 units), an increase in frequency of tripping due to breaker fault (0.41 units), increase in total frequency of tripping within the system, which increased from -0.33 to -0.14 units, increase in the total fault duration of breaker faults (0.34 units) and increase in the total fault duration in the system, which is from -0.09 to 0.08 units.

Voltage surges, which can be caused by lightning strikes, switching operations, or other transient events, can result in an overvoltage condition. Circuit breakers are designed to protect the electrical system from overvoltage by tripping when the voltage exceeds a certain threshold. If the surge is severe enough, it can cause the circuit breaker to trip, interrupting the power supply. Voltage surges can lead to arcing across the contacts inside the circuit breaker. Arcing can erode the contacts and reduce their effectiveness over time. Prolonged exposure to voltage surges can accelerate contact wear and eventually lead to the need for maintenance or replacement of the circuit breaker. High-voltage surges can also exert mechanical stress on the circuit breaker's components. The rapid and severe changes in voltage and current can impact the moving parts of the circuit breaker, affecting its mechanical integrity.

From Fig. 14, an increase in preventive maintenance carried out on breaker, training of operation and maintenance team, better town planning, co-operation between community and EKEDP and well secured environment within the system would lead to a decrease in the breaker fault (-0.22 units), decrease in cable vandalized fault (-0.85 units), decrease in frequency of tripping due to breaker fault (-0.13 units), decrease in frequency of tripping due to cable vandalized (-0.69 units), decrease in total frequency of tripping from -0.14 to -0.39, decrease in the total duration of breaker faults (-0.11), decrease in the total fault duration of cable vandalized faults (-0.18) and decrease in the total fault duration from 0.08 to -0.14.

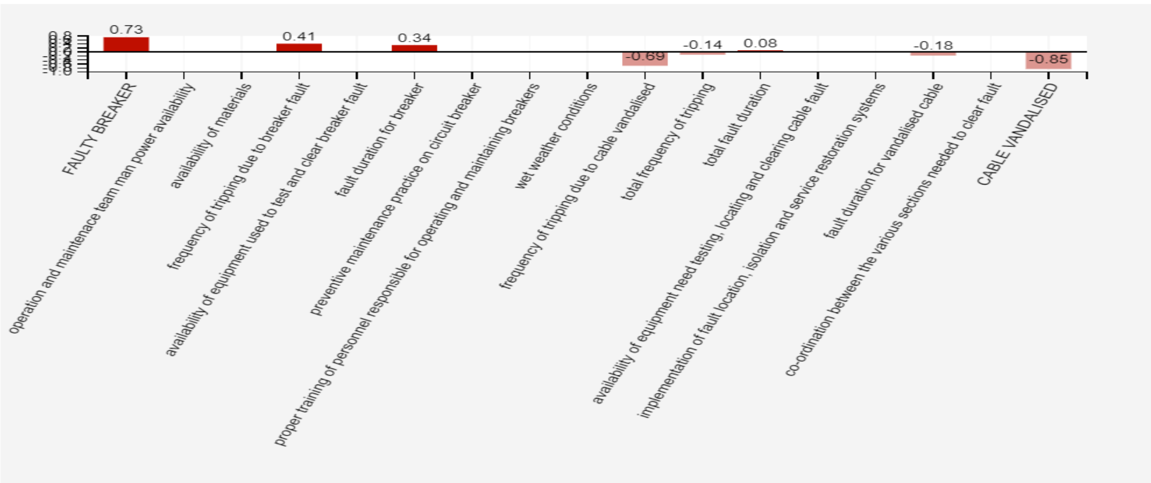

Fig. 13: Bar chart showing the impact of high fault current from short circuits, mechanism issues, voltage surge, better town planning, co-operation between communities and EKEDP, and a secure environment on the system.

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Preventive maintenance practices for 11kV fdr circuit breakers are crucial to reduce the frequency of tripping due to breaker faults and ensure the reliable operation of the electrical distribution system. Regular inspection of the circuit breaker for signs of physical damage, loose connections, or loose parts would reduce the frequency of tripping due to a faulty breaker. Keeping the circuit breaker and its surroundings clean and free from dust, dirt, and debris, ensuring proper ventilation and cooling systems are functioning correctly to prevent overheating of the circuit breaker.

From Fig. 15, the increase operation and maintenance manpower availability, better coordination between sections to clear fault, availability of equipment to clear breaker fault, availability of equipment to clear cable fault, implementation of Fault Location, Isolation, and Service Restoration (FLISR) systems will lead to decrease in the fault durations of breaker fault (-0.22 units), decrease in fault duration of cable vandalized (-0.85 units) and decrease in the total fault duration in the systems (-0.75 units).

With reference to Fig. 16, an increase in wet weather conditions will lead to an increase in fault durations of cable-vandalized faults, from -0.97 to -0.92, and an increase in the total fault duration in the systems, from -0.75 to -0.74.

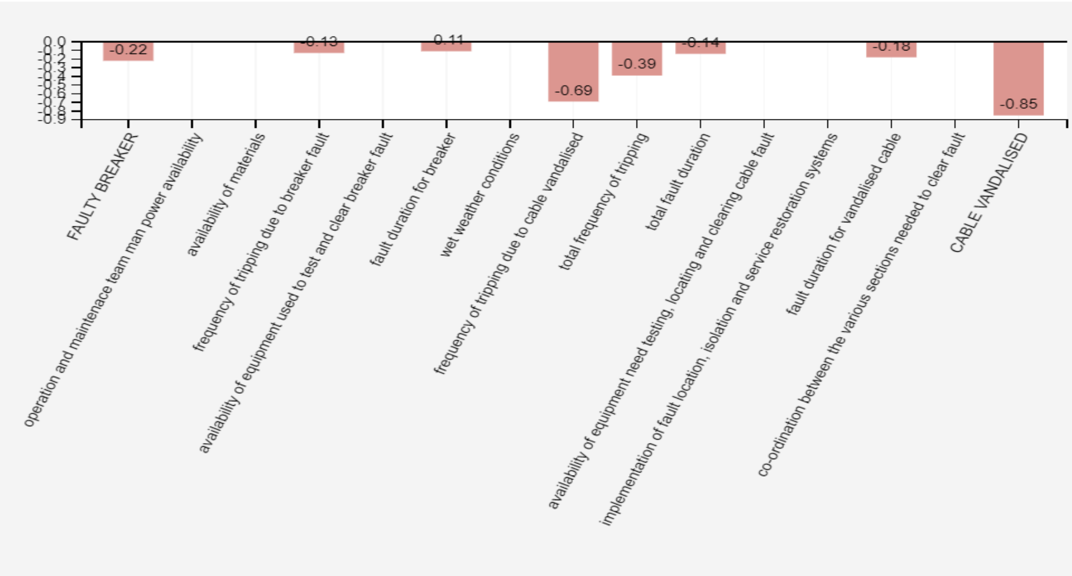

Fig. 14: Bar chart showing the impact of preventive maintenance of breakers, training of the operation and maintenance team, better town planning, co-operation between communities and EKEDC, and a secure environment on the system.

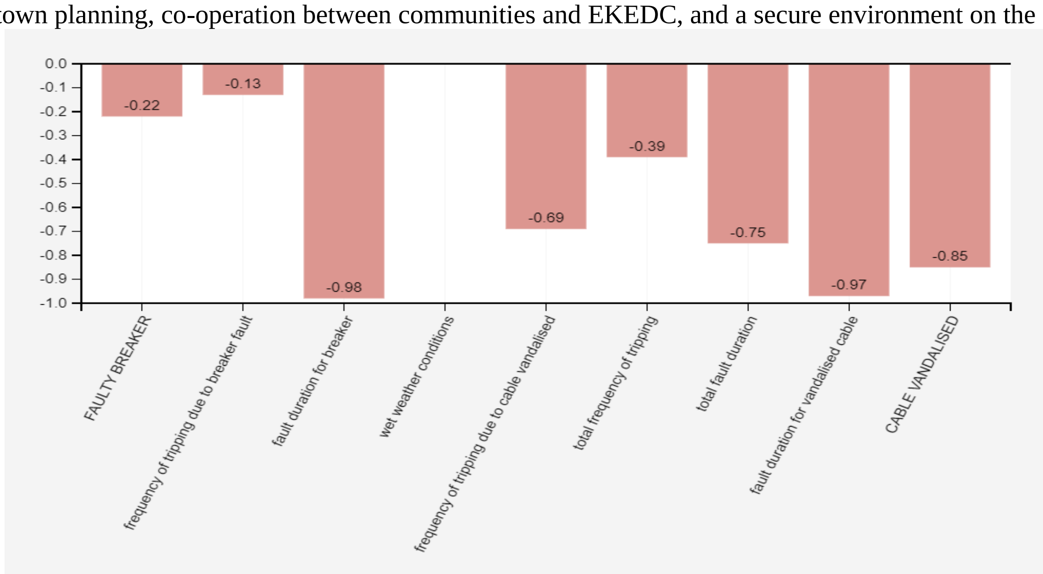

Fig. 15: Bar chart showing the impact of manpower availability, better coordination between sections to clear faults, availability of equipment to clear breaker faults, availability of equipment to clear cable faults, and implementation of Fault Location, Isolation, and Service Restoration (FLISR) systems.

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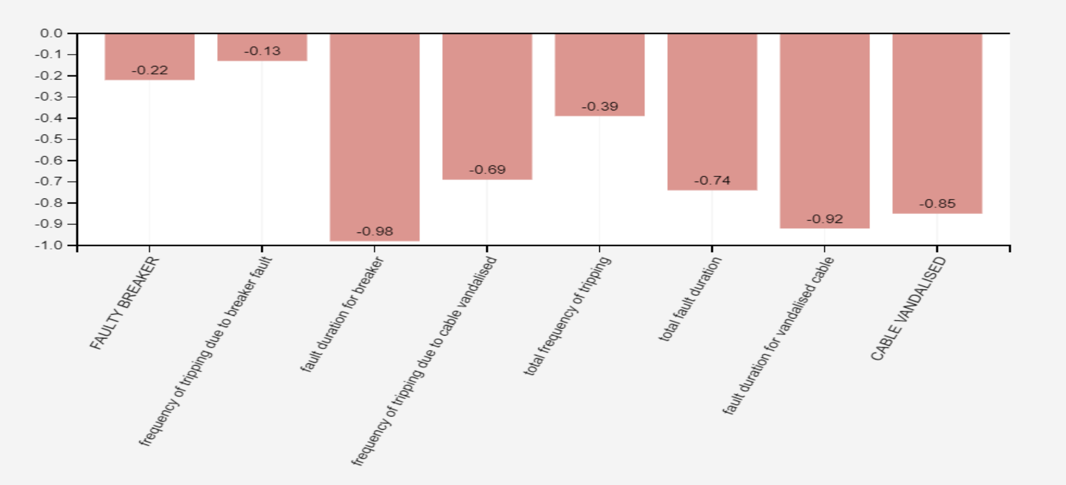

Fig. 16: Bar chart showing the impact of wet weather conditions

V. CONCLUSION

This study analyzed the forced outages of 11kV fdrs within EKEDP network, within a period of five years (2020-2024). The dominant fault causes were identified as jumper cut, transient faults, cut J&P, and line fuse operations, RMU cable end box explosions, HT mainline cut, and tree contact with the lines. Ogombo, Moore Road, SPG, Langbasa, and Adeola Hopewell fdrs recorded the highest tripping frequencies, indicating higher operational vulnerability. Monthly analysis showed that April, May, and June had the highest forced outage occurrence rates, suggesting a correlation between wet weather and increased forced outages. Computed ENS revealed significant revenue losses, potentially amounting to billions of Naira over the study period.

Jumper cuts are likely due to poor mechanical clamping, corrosion at aluminium–copper interfaces, thermal fatigue, and overloading. To mitigate this, it is recommended that critical sections (jumpers) where loading is high (particularly the first Upriser jumper of each fdr) be reinforced with 240 mm² Aluminium Conductor Steel Reinforced (ACSR) in place of the existing 150 mm² conductors. The use of standard bimetallic line taps is also advised instead of improvised aluminum strand joints to ensure proper conductivity and mechanical strength. Transient faults, which occur predominantly on overhead lines, are often linked to overspanning, conductor sag, and vegetation contact. Proper tensioning of conductors, installation of interpoles along long spans, and routine tree trimming should therefore be prioritized. The adoption of GIS-based (Geographical Information System) vegetation management and stronger community engagement for right-of-way enforcement will further reduce vegetation-related disturbances.

Frequent J&P and line fuse operations due to downstream LV faults indicate poor protection selectivity. Protection coordination studies should be conducted to recalibrate devices appropriately. In addition, the deployment of reclosers and sectionalizers (especially on long fdrs) will enhance fault isolation and minimize outage spread. RMU Cable end box explosions, largely attributed to moisture ingress, can be mitigated by replacing heat-shrink termination kits with cold-shrink termination kits and implementing a moisture-detection and preventive-maintenance program. To address mainline cuts, the use of 150mm^2 ACSR conductors is recommended to replace 150mm^2 Aluminium conductor for improved mechanical strength. Furthermore, replacing porcelain insulators with silicon rubber insulators will reduce failures caused by cracking, contamination, and weather-related deterioration. Collectively, these measures will enhance fdr reliability, reduce ENS, and minimize revenue losses across 11kV DN.

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