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CAUSES AND IMPLICATIONSOF FAULT TRIPPINGS IN A TYPICAL ELECTRICITY DISTRIBUTION NETWORK: USING GRA 33/11KV FEEDER AS CASE STUDY

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Abstract

This research is aimed at investigating the major causes of fault, effect and the financial implications using a typical 33/11kV feeder as case study. Comprehensive study of GRA 33/11kV feeders (Reservation 11kV feeder, GRA 11kV feeder, Oba Palace 11kV feeder, Ihama 11kV feeder and Dumez 11kV feeder) in the distribution network of Benin Electricity Distribution Company (BEDC) was carried out. The causes and frequency of fault tripping were evaluated, including load loss and downtime. The estimated cost implication due to fault tripping of the selected feeders from January 2017 to December 2017 was also determined. Result of the research showed that the faults in the various 11kV feeders were largely due to vegetation, broken poles, broken cross-arms, wire cut, vehicular collision and transient fault. The result suggests that the Reservation feeder is more prone to tripping as compared to other 11kV feeders in the case study. The financial implication of the downtime on the service provider and customers on diesel and gasoline for the year under review is ₦2,299,439,126.3and ₦12,427,711,631.3 for diesel and ₦30,595,270,201 for gasoline respectively.

***Keywords*:** Downtime, Electricity Distribution Network, Fault Tripping, Feeders, Load Loss.

1. INTRODUCTION

The power industry is an important sector in a country which plays vital role in Nation building and economic development. Lack of reliable power supply can have negative effect on its economy [1]. For Nigeria to be identified as developed nation, its power sector needs to be revamped to the level of giving 24-hour uninterruptable power supply as this will have positive effect on the country's socioeconomic growth [2]. The current state of the Nigerian power sector is deplorable and the amount of power generated in the country does not measure up to the required amount that would allow 24-hour supply [3, 4]. As a result, residents and other consumers in need of electricity can hardly predict when there will be power supply for use, and the period of uninterrupted power supply are way less than the periods when it is not available [3, 5]. In 2017, Nigeria Power Generation statistics showed that an average of 3687MW of energy was generated and this is way below the required 160,000MW of electricity required for a population of over 160 million people in Nigeria [6].

The most unfortunate of this scenario is the fact that even the available power is not efficiently distributed because the supply networks of electricity are prone to some disturbances which directly has effect on energy availability [7]. One of the major causes of unstable power supply in Nigeria is the incessant tripping of feeders (both 11kV and 33kV) [8]. There are many factors that cause fault or tripping in the distribution network; they can be classified as technical and non-technical causes [9]. The distribution network of Benin Electricity Distribution Company (BEDC); one of the eleven electricity distribution companies in Nigeria will be subject of investigation in this research. BEDC network covers four states; Edo, Delta, Ondo and Ekiti states. The network has an installed injection capacity put at 1,255.31MVA, while a total installed capacity of distribution is 1,564.4MVA [10].The tripping of feeders connected in its network affects a large number of people and businesses in the coverage area.

The high frequency of fault tripping of feeders increases the overall running cost on the part of the customer and the utility company. The BEDC electricity network suffers from tripping; some as a result of earth fault, over current fault, transient faults, etc. Some causes of these faults can be attributed to nature, animal or human, vegetation, etc. This has resulted to loss

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of customer goodwill and poor image of electricity of the electricity distribution company. The causes and effects of network failure may have been deemed inconsequential by the utility and the customers, it is therefore expedient to evaluate and analyze the overall causes and impact of faults on the distribution system [11]. There is need to identify the prevalent causes of fault, frequency of fault and the financial implications of downtime on the service provider and customers.

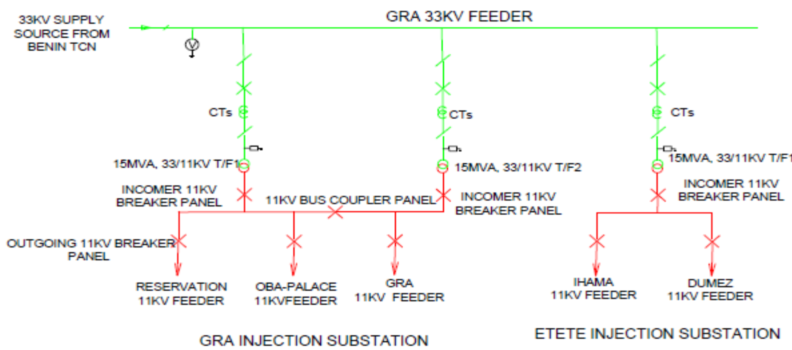

Figure 1: Single line diagram showing GRA 33kV feeder and associated injection substation and 11kV feeders [12].

2. METHODS

A study of GRA 33kV feeder and its associated 11kV feeders (Reservation 11kV feeder, GRA 11kV feeder, Oba Palace 11kV feeder, Ihama 11kV feeder and Dumez 11kV feeder) in the distribution network of BEDC was carried out. Data centered on fault tripping were collected from BEDC control rooms and analyzed (BEDC, 2017).

i) Site visitation to the selected feeders to ascertain the true condition of the network was done.

ii) Frequency of fault tripping per month for each feeder was collected, tabulated and a chart representation were presented for comparison amongst the feeders as shown in table1 and Figure 2 respectively.

iii) Downtime caused by the fault tripping was calculated using Equation (3) and results are tabulated as shown in Table 2.

iv) Amount of average load loss (kWh) was evaluated using Equation (4) and the results are as tabulated in Table 3.

v) Causes of fault tripping (traced and relay indicated) were also evaluated to determine the most prominent. They are as shown in table 5, Figure 5 and Table 4, Figure 6 respectively.

vi) The estimated economic cost implication of the fault tripping on the selected feeders was determined from two perspectives;

a) Evaluation of cost implication on BEDC by using Equation (6)

b) By determining the cost incurred by the customers as a result of private generator usage due to feeder downtime Equation (8).

2.1 Data presentation

The data collected are as presented in the tables shown below;

Table 1: Monthly Frequency of Tripping on the 11kV Feeders for the Year 2017 [12].

	11kV Feeders (frequency of tripping)				
Month	**GRA**	**Oba Palace**	**Reservation**	**Ihama**	**Dumez**
Jan	4	7	26	8	3
Feb	12	12	47	8	7
Mar	5	9	34	8	7
Apr	13	5	26	8	8
May	8	4	17	6	5
June	7	4	25	11	8
July	7	7	16	11	12
Aug	12	3	18	19	14
Sep	5	6	24	7	9
Oct	11	5	16	13	27
Nov	8	5	26	6	8
Dec	8	3	15	4	4
Total No. of trippings	**100**	**70**	**290**	**109**	**112**

Table 2: Downtime of the 11kV Feeders on Monthly Basis [12].

	Name of 11kV feeders (Downtime (Hrs) for each month in 2017)				
Month	**GRA**	**Oba Palace**	**Reservation**	**Ihama**	**Dumez**
Jan	2.84	35.2	67.6	9.1	18.2
Feb	16.7	82.4	163.5	42	19.2
Mar	40.27	31.08	152.9	55.7	2.15
Apr	61.2	6.98	91.5	44.4	24.3
May	20.5	39.1	29.2	11.4	13.8
June	85.93	12.6	143.9	56.2	41.25
July	65.9	72.67	96.72	20.68	98.1
Aug	62.4	20.6	75	56	82.5
Sep	13	2	110.1	2.9	60.9
Oct	55.3	46.2	102.4	26.4	143.3
Nov	56	42.4	167.8	19.2	165.3
Dec	59.9	35.12	82.9	4.13	28.13
Total downtime per feeder	**539.9**	**445.5**	**1283.6**	**348**	**697.2**

Therefore, **total downtime for entire feeders = 3314.2Hrs**

Table 3: Average Load Loss on 11kV Feeders in 2017 [12]

	11kV Feeders (Average load loss (kiloWatt) for each month in 2017)				
Month	**GRA**	**Oba Palace**	**Reservation**	**Ihama**	**Dumez**
Jan	3935.32	4247.86	6913.51	3800.89	3044.60
Feb	3951.50	3692.39	7274.65	3846.24	3039.74
Mar	3915.87	3930.45	6524.83	3740.97	2915.04
Apr	3169.30	3381.45	6281.91	3862.43	3098.04
May	3130.43	3206.55	5875.43	3579.02	2801.68
Jun	2769.29	3627.61	4568.52	3357.16	2905.32
Jul	2526.37	2817.87	5308.61	3030.02	2170.09
Aug	2131.22	2817.87	6272.20	2838.93	2401.67
Sep	2079.40	2089.11	5843.04	2706.13	2312.60
Oct	2296.40	2976.58	5689.19	2915.04	2542.56
Nov	2939.33	3089.94	6168.55	3692.39	2349.85
Dec	2965.25	3481.86	6038.99	3959.60	2348.23
Total	**35809.67**	**39359.54**	**72759.44**	**41328.81**	**31929.42**

Total load loss for the entire feeders = 221186.9kW

Table 4: Frequency of Relay Indicated Fault Causes of the 11kV Feeder 2017 [12].

	Cause of fault tripping/relay indication recorded	
Name of feeder	**Earth fault**	**Overcurrent/overload**
GRA 11KV feeder	85	15
Oba Palace 11kV feeder	62	8
Reservation 11kV feeder	267	23
Ihama 11kV feeder	97	12
Dumez 11kV feeder	100	12

Table 5: Frequency of Various Traced Fault Causes of Fault Tripping of 11kV Feeder[12].

Major reasons recorded for 11KV feeders fault tripping in 2017	GRA 11KV feeder	Oba Palace 11kV feeder	Reservation 11kV feeder	Ihama 11kV feeder	Dumez 11kV feeder
Transient (due to Overload)	49	30	207	82	80
Animal Bridges		2	1		1
Falling tree/Vegetation Interference	7	2	4	4	3
Jumper/Upriser Cut	7	8	26	3	6
Others (Broken Poles, Wire cut, Vehicular Collision, etc.)	37	28	52	20	22

2.2 Comparisons of the various feeders on charts

The following charts show the comparisons among the 11kV feeders under case study.

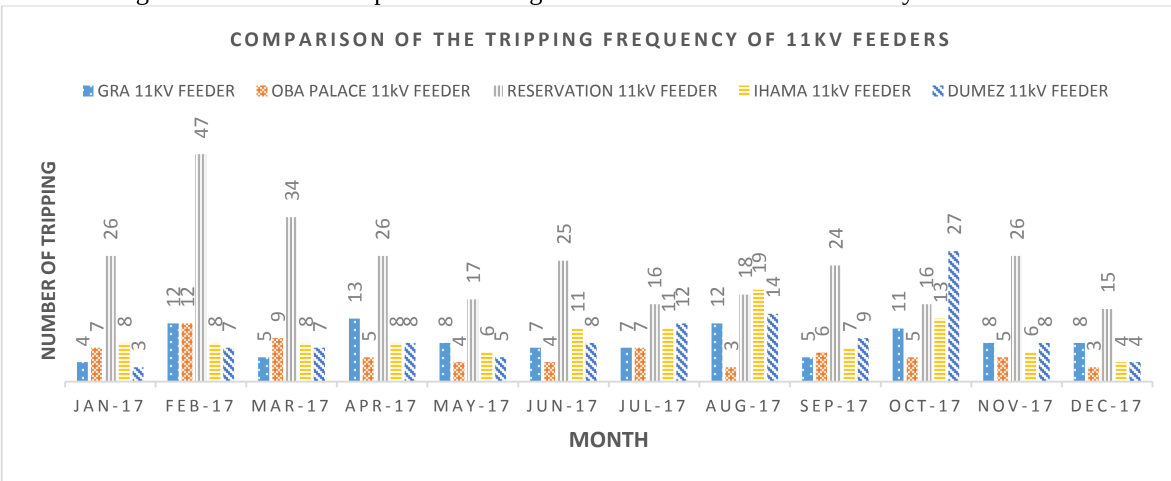

Figure2: Chart Showing the Comparison of Frequency of Fault Tripping of 11kV Feeders

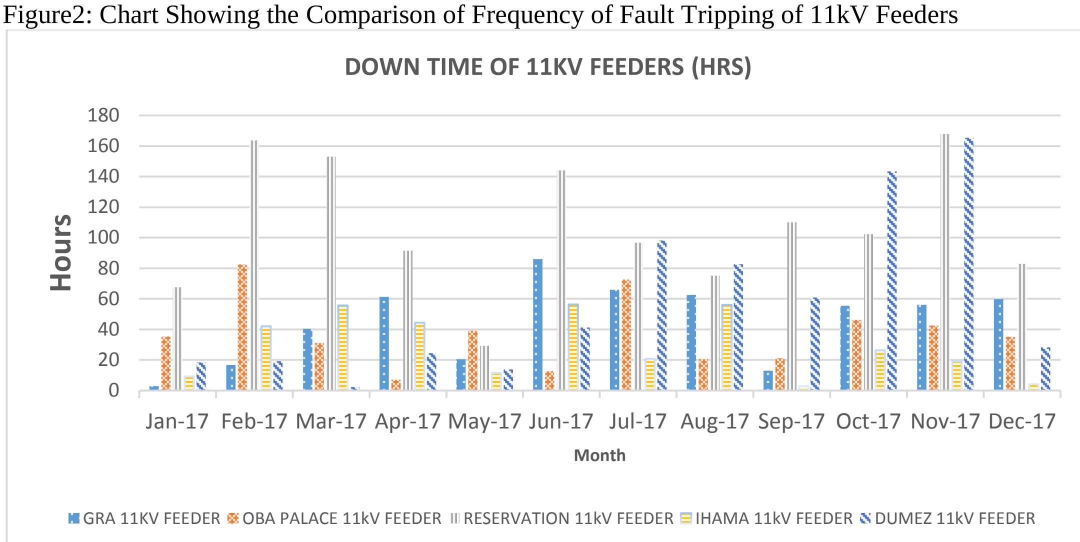

Figure3: Chart Showing the Comparison of Downtime due to Fault Tripping of 11kV Feeders

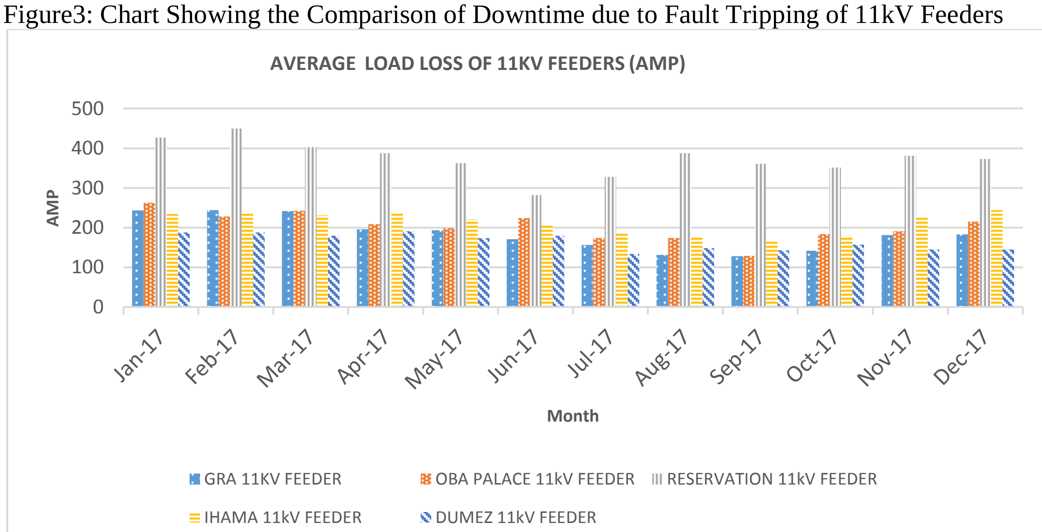

Figure 4: Chart showing the comparison of average monthly load loss due to fault tripping of11kV feeder.

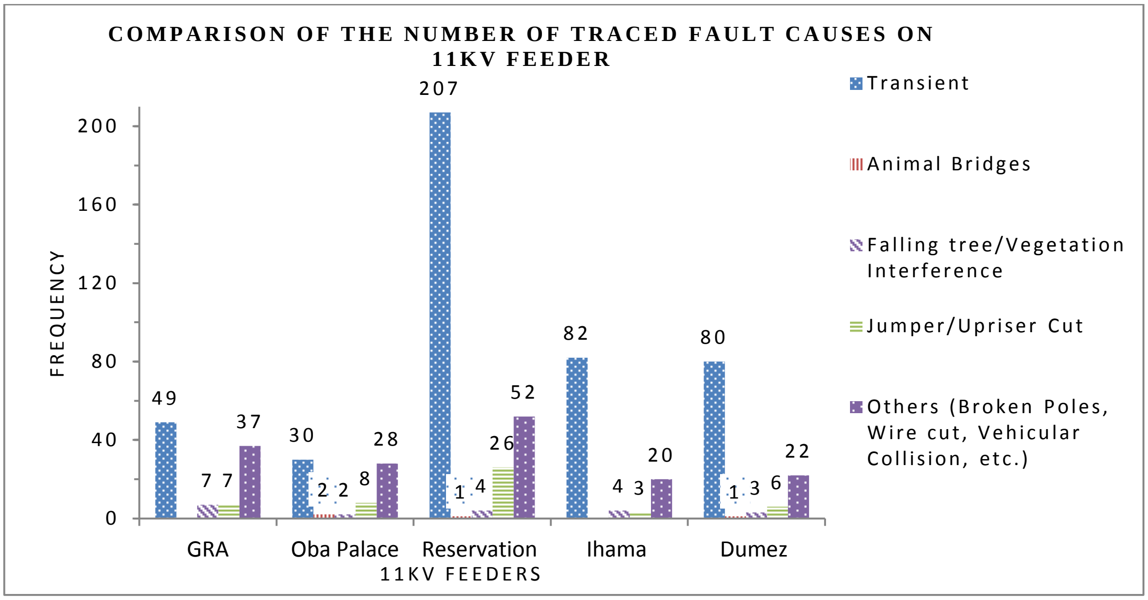

Figure5: Chart showing the comparison of the number of traced fault causes on 11kV feeder.

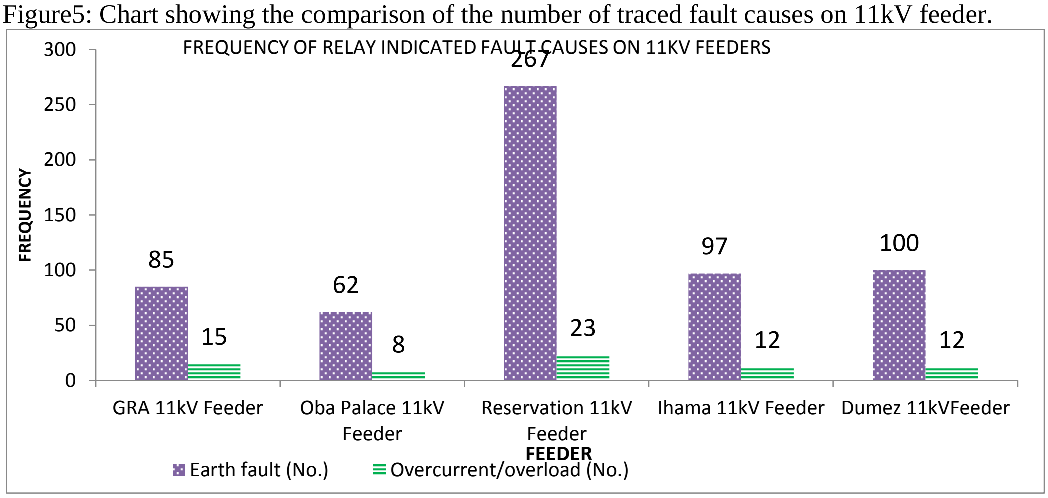

Figure6: Chart showing the comparison of the frequency of relay indicated causes of fault on 11kV feeders.

3. RESULTS AND DISCUSSIONS

3.1 Result and discussions of the 11kV Feeders

Table 1 and Figure 2 show that Reservation 11kV feeder is more prone to tripping as compared with other 11kV feeders in the case study as shown in Tables 1 to Figure 3 and Figure 1 to Figure 4 respectively. Part of the reasons for this is that the Reservation 11kV feeder is 18.2km in length as compared to GRA, Oba Palace, Ihama and Dumez with feeder lengths of 11.9km, 7.2km, 16.2km, 8.6km respectively. The Reservation feeder is also grossly overloaded. In the year under review, the feeder had a total tripping frequency of 290, downtime of 1283.61hrs and load loss of 72759.44 kW. With the lowest frequency of tripping put at seventy (70) hours in the year 2017, Oba Palace 11kV is less prone to tripping as compared to other 11kV feeders such as GRA, Reservation, Ihama and Dumez which recorded a total number of tripping of 100, 290, 109 and 112 times respectively

From Table 5 and Figure 5, it can be seen that a good percentage of the causes of fault in the network is transient. This means that the cause of tripping was not found after the patrol and inspection of the feeders. Interactionwith the Distribution System Operator (DSO) shows that this is how faults whose actual cause cannot be verified are recorded. Therelays indicated earth fault in a greater number of the tripping as seen in Table 4. This suggests that the causes of fault tripping may have been as a result of vegetation, trees/climbers and animal activities interfering with the line at some point along its length. With a good number of faults resulting from broken poles, wire cut etc in Table 5 and Figure 5, it is evident that a good number of the power system components on the network required overhauling. These causes can as well be indicated by the relay as earth fault.

3.2 Estimated cost implication per feeder

3.2. 1Definition of some related concepts.

Frequency of faults: This refers to the total number of tripping due to fault for the feeders under consideration. For a one month period, frequency of fault is given by:

$F_m = \sum_{d=1}^{n} f_d$ (1)

F_m = Frequency of faults per month,

f_d = No. of fault tripping per day.

d represents days of the month=1,2,3…n

And n is the last day of the month.

m=1,2,3…12 are months of the year.

Downtime of feeders

This represents the period of time when the feeder remains inactive due to fault i.e. the time span between the moment the feeder trips and the moment when the feeder is restored. Therefore;

D = H-T (Hrs.) (2)

D = Downtime of feeders.

T = Time Out (The time of day at which the feeder tripped).

H = Time in (The time of day at which the feeder was restored). For a period of one month, downtime is given by:

$D_m = \sum_{d=1}^{n} D_d$ (3)

D_m = Downtime of feeders per month.

D_d = Feeder downtime due to fault trippings per day.

d = days of the month=1,2,3..., n. And n is the last day of the month. Where m=1,2,3…12 are months of the year.

Average load loss

This refers to the average load interrupted as a result of fault tripping of the feeders. This is given by total load interrupted during fault tripping divided by total number of fault tripping.

Average Load Loss per month,

$A_m = \frac{L_m}{F_m} = \frac{\sum_{i=1}^{t} L_i}{F_m}$ (4)

L_m = Total load interrupted for all fault tripping per month.

F_m = Frequency of fault trippings for the month.

m=1,2,3…12 are months of the year. i=1,2, 3…t represent tripping

3.3 Economic implication of fault tripping

The economic implication is the net income (in naira) that BEDC may have lost due to fault tripping of the feeders. From the customers' perspective, it is the extra cost incurred in running private generators during downtime. This cost implication excludes the cost of restoring the feeder to supply. Mathematically, the various cost implications are represented below;

a) Estimated cost implication on BEDC:

Cost implication (or loss of income) on BEDC = Load loss in kW x downtime duration in hr. x average prevailing charges per unit on 11kV residential customers – average prevailing Transmission Use of System (TUOS) charge per mega Watt of Nigeria (5)An average of the monthly record of ATC&C losses was taken for the year in view.

Estimated cost implication on BEDC = Cost implication – ATC&C losses (55.25% of cost implication) [13]. (6)

ATC&C losses = Aggregate Technical Collection and Commission losses,

b) Estimated cost implication on customers due to downtime (faults)

i)Assuming all affected customers on the affected feeder depend on diesel;

Cost implication on customers = Load loss in kW x downtime x(running cost of diesel per kWh -average prevailing charges per unit on 11kV residential customers) (7a)

ii)Assuming all affected customers on the affected feeder depend on gasoline;

Cost implication on customers = Load loss in kW x downtime x(running cost of gasoline per kWh -average prevailing charges per unit on 11kV residential customers) (7b)

1) GRA 11kV feeder:

a) Estimated cost implication on BEDC:

From Table 3, Load loss (Watts) = 35,809,665.47Watts for GRA feeder.

Load loss (W) = 35,809.7kW = 35.8097megaWattsFrom Table 2, downtime for GRA 11kV feeder = 539.86hrs.

Average Unit charge/kW-hr. = 34.40 naira [14].

Transmission Use Of System (TUOS) charge/megawatt-hrin Nigeria (2017) = 3,613.47 Naira (₦)[15].

Applying Eq. (5) above,
Cost implication= 35,809.7 x 539.86 x 34.40- (35.8097 x 539.86 x 3,613.47)= ₦ 595,172,113.9
Considering estimated
ATC&C loses of 55.25% in 2017;
55.25% x ₦ 595,172,113.9 = ₦ 328,832,593
Therefore;
Estimated Cost Implication = Cost Implication – ATC&C lose cost Implication
Estimated Cost Implication = ₦ 595,172,113.9 -₦ 328,832,593
Estimated Cost Implication = ₦ 266,339,520.9

b) Estimated cost implication on customers as a result of downtime:

The cost of generating electricity by customers (private individuals) during downtime is put at USD 30 cents/kWh and USD 60 cents/kWh (an equivalent of 108.86 Naira and 217.71 Naira) for diesel and gasoline respectively [16]. These figures were used in carrying out the following calculations; **i) Assuming the entire customers on the feeder depend on diesel;** Cost implication on customers = 35,809.7x 539.86x (108.86 – 34.4)
= ₦ 1,439,477,446.84

ii) Assuming the entire customers on the feeder depend on gasoline;

Cost implication on customers = 35,809.7x 539.86 x(217.71 – 34.4)
= ₦ 3,543,790,099.13

Similar steps were applied for the estimated cost implications of the rest 11kV feeders. Thus, the results are as tabulated below;

Table 6: Estimated cost implication of the GRA 11kV feeder downtime in 2017

		Estimated cost implication on customers	
Names of 11kV feeders	**Estimated Cost implication (₦) on BEDC**	**Diesel(₦)**	**Gasoline(₦)**
GRA	266,339,520.9	1,439,477,446.8	3,543,790,099.1
Oba Palace	241,574,730.5	1,305,631,905.7	3,214,281,287.1
Reservation	1,286,686,776.1	6,954,118,519.5	17,120,057,290
Ihama	198,146,281.2	1,070,915,431	2,636,442,488.1
Dumez	306,691,817.6	1,657,568,328.3	4,080,699,036.6
Total estimated cost implication	**2,299,439,126.3**	**12,427,711,631.3**	**30,595,270,201**

4.2.3 Total estimated cost implication

From Table 6 above, it can be seen that Reservation 11kV feeder recorded the greatest cost implication on both the supplier (BEDC) and customers as a result of frequent tripping, as against that of Ihama 11kV feeder which recorded the least. Overall, the utility company (BEDC) is estimated to suffer a loss of₦ 2,299,439,126.3 due to frequent tripping of GRA 11kV feeders, while the sum of ₦ 12,427,711,631.3 and ₦ 30,595,270,201 were estimated on the part of customers if the assuming they all depend on either diesel or gasoline respectively.

5. CONCLUSION

Considering the estimated cost implication of fault tripping of the feeders, it is observed that the cost implication of fault tripping of reservation 11kV feeder is more as compared to other 11kV feeders on the network. This is a direct consequence of the longest downtime and higher frequency of tripping experienced by reservation 11kV feeder as compared to the other feeders. It is recorded that Reservation 11kv feeder (18.2km) is longer than the other 11kv feeders; GRA, Oba Palace, Ihama and Dumez with feeder lengths of 11.9km, 7.2km, 16.2km, 8.6km respectively. This is a contributing factor to the longer downtime of reservation 11kV feeder as compared to other 11kV feeders. Following the astronomical estimated cost implications on the part of the service provider and consumers, efforts need to be made to ensure that fault tripping is reduced to the barest minimum.

To forestall the incessant tripping of the feeders and also avoid the prolong downtime and man-hour loss, system components like insulators, conductors, should be checked on regular basis for weaknesses and inherent failures. This can lead to a reduction of earth fault and over current. With fault tripping in distribution networks largely caused by transient faults, uncoordinated tripping, accident and broken parts of network facilities, routine maintenance should be carried out regularly on system components. Weak poles and cross arms should be replaced to avert failure due to storm. System hardware like wooden poles, crack concrete poles and undersized conductors that are prone to snapping and breakage should be changed from time to time.

Accidents should be avoided as much as possible by observing the minimum distance of right of way of the power system utilities. Maximum lengths of 11kV feeders should be limited to 5km as this will allow for ease of fault tracing, fault clearing and ease of maintenance.

Appropriate sanctions should be put in place to deter offenders who deliberately destroy and vandalize utility infrastructures from doing so. Feeder conductors should have enough clearance between phases to reduce cases of short circuit of phases.

Adequate "trace-clearing and trace-widening" around 11kV and 33kV feeder networks should be done. This will reduce the occurrence of earth fault and hence reduce the frequency of fault tripping of the feeders.

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