Reliability Assessment of 33KV Feeder, (A Case Study of Transmission Company of Nigeria, Ganmo Work Centre.)

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***Abstract*— According to statistics, about 80% of the power interruptions result from power distribution system failure. Historical assessment and predictive methods are normally used to evaluate the reliability of a distribution network. Most utilities focus more on historical assessment rather than predictive methods. Hence, it is vital in design and development of distribution network to study and analyse the reliability.**

This research adopted methods involving analysis and evaluation of reliability of one of the Nigeria transmission station (Ganmo 33KV Ilorin) feeders to see how reliability could be improved in the distribution system by incorporating reliability analysis in the systematic planning approach so that optimum reliability is achieved. Analytical method such as Markov model and reliability indices of each feeder was evaluated, assessed and compared to see how risk of failure could be reduced. The reliability indices for the year 2016 and 2017 are being considered as the case study.

The outages on the TCN Ganmo 33KV feeders was studied for 24 months on daily outage data collected from the station. Based on the result obtained from the data analysis illustrated with graphs, it was deduced that dedicated feeders such as KAM and UNILORIN have the highest reliability and more available compared to others residential feeders. This can be attributed to the level of their load demands. Generally, the feeders have least reliability during the period of May to October due to high vegetation and rainfall.

***Index Terms*— Cumulative fault frequency, data analysis, data analysis, Transmission, dedicated feeder, Marcov chain model.**

I. Introduction

Highlight Electrical systems are one of the most complex infrastructures around the world and they are expected to operate with high quality and reliability. The main purpose of power system is to provide economical and reliable channel for electrical energy to move from the generation point to consumer ends. The economical and reliability constraints can be mutually competitive, making planning and operation of power systems a complex problem (Och, 2017).

The distribution system reliability evaluation considers the ability of thedistribution system to transfer energy from bulk supply points such as typical transmission system end-stations, and from the location of generation points, to consumer ends. The ability of the system to provide appropriate level of supply of electric energy is determine by the term reliability (Dorji, 2009).

Most utilities focus more on historical assessment rather than predictive methods. Hence, it is vital in design and development of distribution network to study and analyse the reliability. Alert, knowledge of the reliability analysis of distribution system helps to measure how much the system meet the performance criteria, which will help to compare the different options and help in terms of economic decision. In addition, the reliability analysis result will determine the failure rate and mean failure duration for particular equipment or group of equipment, thus with more detail in databases, the information gained may be important for utilities operators, such as the most frequent cause of failures, areas of greatest amount of undelivered energy or the most weakness area of protection system which contribute to interruptions and fault

II. Source of Data and Data Collection

The primary source of data for this study is Transmission Company of Nigeria Ganmo work centre. The data collected consist of circuit breaker tripping report and system line outages of each feeder. The circuit breaker tripping report comprises of number of power interruption, causes of fault and duration of outages hourly.

Data Analysis: The data collected in section was used in Microsoft Excel to developed data Tables, bar chart, pie chart and line chart for different types of analysis like reliability, availability and maintainability of the network. Each of the method used to perform analysis on data gathered from TCN Ganmo were discussed in the following sections.

Markov Chain Model: Markov model was used to represent the two states and determination of the reliability indices of the system. The main reason for this is because simulation generally requires largeamount of computing time, and analytical models and techniques have been sufficient toprovide planners and designers with results needed to make objective decisions. Analyticaltechniques represent the system by a mathematical model and evaluate the reliability indicesfrom this model using direct numerical solutions. They generally provide expectations indicesin a relatively short computing time.

A Markov model is quite popular in the quantitative reliability analysis. The model is suitable when it comes to giving fair idea about reliability analysis principle. On the basis of Markov models, a simple formula can be developed that can be used to calculate the reliability of the radial distribution network. The method is called duration-frequency technique, and the starting point is the

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determination of failure of the individual component. Markov process basically operates with two central concepts:

- Failure rate (λ)
- Repair time (r)

It is assumed in this work that the feeder can only be in one of the following conditions;

- Condition 1: Operating condition (ON)
- Condition 2: Repair condition (OFF)

These two conditions are depicted in figure1where, **0** (feeder in failed state) and **1** (feeder is in a normal state).

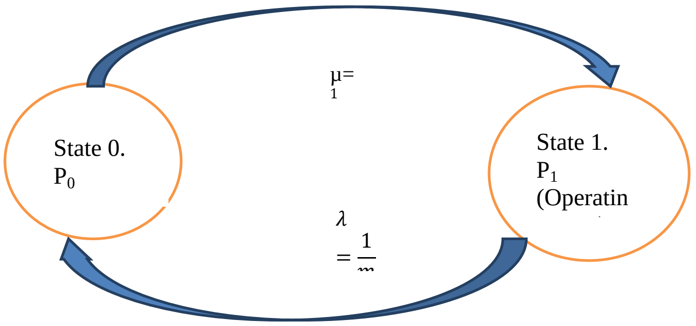

Figure1: Transition diagram of feeder states

In the figure1: λ is failure rate, m is mean time to failure, μ is repair frequency, r is mean time to repair.

where,

$$\lambda = \frac{Cummulative \;\; Fault \;\; freqency}{Period \;\; of \;\; Occurence} \qquad (i)$$

Figure1 illustrates expected functionality and outage time for a feeder. The system is represented by Markov process and equations develop for the probabilities of residing in each state in terms of state transition rates are as follow

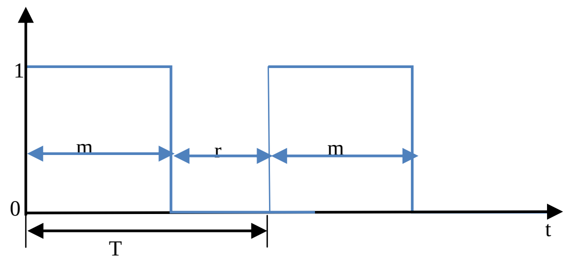

Figure 2: Average state cycle.

Figure 2 is showing average state cycle of the system. The average function time, m, is given by; $m = 1/\lambda$

Where, m = Mean Time to Failure (MTTF) = $1/\lambda$

r = Mean Time to Repair (MTR) = $1/\mu$

:. $m + r = T = 1/f$

f = cycle frequency = $1/T$

T = cycle time = $1/f$

The probability of component to be in either one of the two states can be expressed as;

From figure2 above the probability of state 0 can be deduced from state transition equation

State 0

$P_0\mu = P_1\lambda$ (ii)

Where $\mu=1/r$ and $\lambda=1/m$

Substitute equation 2 in 1 and make P_0 as subject of the formula we have;

$$P_0 = \frac{P_1\lambda}{\mu} = P_1\left(\frac{1/m}{1/r}\right) = P_1\frac{r}{m} \qquad (iii)$$

Since; $P_0 + P_1 = 1$; then, $P_1 = (1 - P_0)$

Substitute P_1 into equation iii

$$P_0 = (1 - P_0)\frac{r}{m} = (r - rP_0)/m \qquad (iv)$$

$P_0 = \frac{r}{m} * \frac{m}{m+r} = \frac{r}{m+r}$ from equation (iv)

$P_0 = \frac{\lambda}{\lambda+\mu} = \frac{\lambda}{T} = \frac{f}{\mu} = \frac{\sum(down \;\; time)}{\sum(down \;\; time)+\sum(up \;\; time)}$ where $f = \mu P_0$

Similarly;

$$P_1 = \frac{m}{m+r} = \frac{\mu}{\lambda+\mu} = \frac{m}{T} = \frac{f}{\lambda} = \frac{\sum(up \;\; time)}{\sum(down \;\; time)+\sum(up \;\; time)}$$

where $f = \lambda P_1$

$f = \mu P_0 = \lambda P_1$ which conform with equation (ii).

where, P_0 = probability for a feeder to be in state 0 (down)

P_1 = probability of a feeder to be in state 1 (up)

f = cycle frequency (frequency to be in or out)

The 33KV feeders in Ganmo are basically designed, constructed and operated in radial system. A radial system basically consists of set of series components like; breakers, lines, switches, transformers and at the end a "Customers". In the series structure both components must be intact for the system to function, "a chain is no stronger than its part".

III. THEORY OF RELIABILITY

Reliability concept is defined as the probability that a system will perform its intended function during a period of running time without any failure. A failure causes the system performance to stray from the specified performance.

A fault is an erroneous state of the system. Although the definitions of fault are different for different systems and in different situations, a fault is always an existing part in the system and it can be removed by correcting the erroneous part of the system. It is acknowledged that reliability is changing due to ageing and maintenance culture of electrical power system and this is observed having studied electrical system for a long period of time.

As part of the assessment of the Ganmo 33KV's reliability, the following indices were determined:

Failure Rate: Failure Rate $\lambda(t)$: The failure rate of a component or system is defined as the probability per unit time that the component or system experiences a failure at time (t), given that the component or system was operating at time zero and has survived to time (t).

$$Failure \; Rate(\lambda) = \frac{cummulative \;\; fault \;\; fequency}{period \;\; of \;\; occurrence} \quad v$$

Mean Time between Failures (MTBF): Mean Time between Failures (MTBF) is a basic measure of reliability for repairable items. MTBF can be described as the time passed before a component, assembly, or system fails, under the condition of a constant failure rate.

MTBF can be calculated as the inverse of the failure rate (λ) for constant fail systems.

$$MTBF = \frac{Total \;\; system \;\; operating \;\; hour}{Number \;\; of ailure} = \frac{1}{\lambda} \quad vi$$

Where, λ is failure rate.

Mean Time to Repair (MTTR): Mean time to repair (MTTR) is defined as the total amount of time spent performing all corrective or preventative maintenance repairs divided by the total number of those repairs. It is the expected span of time from a failure (or shut down) to the repair or maintenance completion. This term is only applicable with repairable systems.

(MTTR) = $\frac{Total\ \ system\ \ downtime}{Number\ \ of\ failure}$ vii

Availability: The Availability A(t), of a component or system is defined as the probability that the component or system is operating at time (t), given that it was operating at time zero. It is often expressed as up-time divided by up-time + downtime with many different variants. Up-time and downtime refer to opposite conditions. Up-time refers to a capability to perform the task and downtime refers to not being able to perform the task(Barringer & Hotel, 1997).

Availability (A) = $\frac{MTBF}{MTBF+MTTR}$ viii

Reliability: This deals with reducing the frequency of failures over a time interval and is a measure of the probability for failure-free operation during a given interval, for instance, it is a measure ofsuccess for a failure free operation. It is often expressed as:

R(t) = $e^{-\frac{t}{MTBF}} = e^{-\lambda t}$ ix

Where,λ is constant failure rate and MTBF is mean time between failure. MTBF measures the time between system failures.

Maintainability: Maintainabilitydeals with duration of maintenance outages or how longit takes to achieve (easy and speedy) maintenance actions. Maintainability characteristics are usually determined by equipment design which set maintenance procedures and determine the length of repair times(Barringer & Hotel, 1997).

The key figure of merit for maintainability is often the mean time to repair (MTTR) and a limit for the maximum repair time. Quantitatively it has probabilities and is measured based on the total down time for maintenance including all time for: diagnosis, trouble shooting, tear-down, removal/replacement, active repair time, verification testing that the repair is adequate, delays for logistic movements, and administrative maintenance delays. It is often expressed as

M(t) = 1- $e^{-\frac{t}{MTTR}}$ = 1 - $e^{-\mu t}$x

Where μ is constant maintenance rate and MTTR is mean time to repair.

IV. Reliability Assessment

Power reliability is the ability of the power system to perform its function under stated conditions for a stated period of time without failure. Distribution reliability is becoming significantly important in the current competitive climate because the distribution system feeds the customer directly. The distribution system is the face of the utility to the customer. Its assessment is to determine the system reliability and customer satisfaction. Analytical treatment of distribution reliability requires well defined units of measurement.

Reliability assessment was made based on the extraction of the data from the daily tripping report of six (6) 33kVfeeders at TCN Ganmo. The monthly reliabilityindices generated from the data collected at the stationbetween January 2016 and December 2017 was computed usingreliability equations discussed above. The table below illustrates the total number of outage experienced by each

feeder spanning the period of twenty-four (24) months.

Table1: Total number of outages of the feeders for 24 months

Name of feeders	**Number of outages**	**Duration of outages**
IDOFIAN	459	2965.09
GRA	172	709.07
INDUSTRIAL	387	1859.87
OGBOMOSHO	582	2748.31
KAM	20	38.22
UNILORIN		792.53

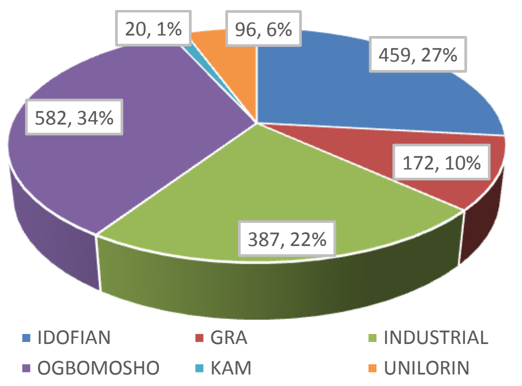

Figure3: Total number of outages of the feeders.

Figure3 shows that Ogbomosho and Idofian feeders recorded the highest percentage of power outages while KAM and Unilorin recorded the least of 1% and 6% respectively. This statistic signifies that the feeders supplying the residential area take large portion of the circle compare to dedicated feeders supplying industrial area. The failure rate of these feeders is in accordance with their number of outages as illustrated in the table2 below:

Table2: Average failure rate of the feeders per year

FAILURE RATE	**2016**	**2017**
IDOFIAN	0.031550218	0.031521358
GRA	0.012908752	0.007627335
INDUSTRIAL	0.023068609	0.02636304
OGBOMOSHO	0.031842043	0.047477196
KAM	0.001832782	0.000457045
UNILORIN	0.005123897	0.006358408

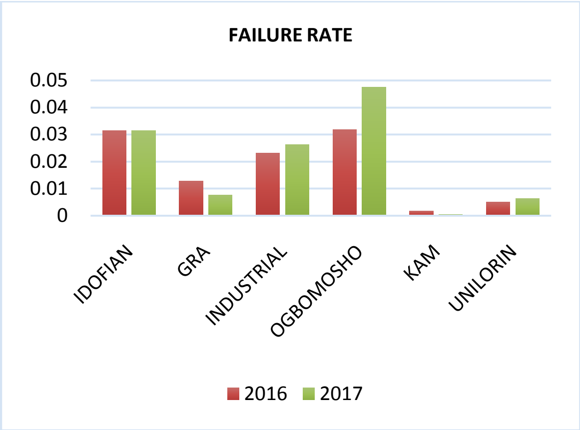

Figure 4: comparison of feeder's failure rate

Figure 4 depicts the failure rate of each feeder comparing the two years of study (2016 and 2017). It was observed that the feeder with highest failure rate has the least MTBF (failure rate is reciprocal of MTBF) which implies that the MTTR of the feeder is high. Therefore, by minimizing the value of MTTR, the service hour can be increased thereby maximizing the overall performance of the feeder. Consequently, the probability that each feeder will be in either normal operating state or failure state as obtained from Markov chain model in chapter is given in the table3 below.

Table3: Average Availability of each feeder per year

AVAILABILITY	2016	2017
IDOFIAN	0.828569635	0.832949772
GRA	0.946227169	0.972828767
INDUSTRIAL	0.895680365	0.892005708
OGBOMOSHO	0.871166667	0.815099315
KAM	0.996563927	0.999073059
UNILORIN	0.957996575	0.951531963

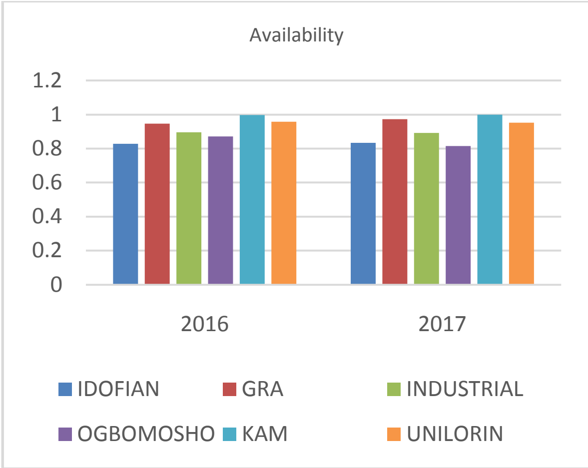

Figure 5: chart of Availability of each feeder against year

Figure 5 shows the annual availability of each feeder. KAM and Unilorin have the highest availability due to low failure rate and less number of outages while Ogbomosho and Idofian have the least availability due to their high failure rate and number of outages. In order to increase the availability of these feeders, their operating hour must be increased, and this can only be achieved by mitigating the duration of outages which is a function of mean time to repair.

After the assessment of each feeder using the reliability indices as discussed above, the equivalent average monthly reliability of each feeder is illustrated in the table4 below. This primarily relates to equipment outages and customer interruptions. In normal operating conditions, all equipment (except stand by) is energized and all customers are energized.

Table 4: Average monthly reliability of each feeder

MONTH	IDOFIAN	GRA	INDUSTRIAL	OGBOMOSHO	KAM	UNILORIN
JAN	0.703785	0.843935	0.71225	0.551205	1	0.934949
FEB	0.492321	0.844925	0.657764	0.550577	0.967129	1
MARCH	0.476736	0.772918	0.462302	0.467312	0.95105	0.887786
APRIL	0.59173	0.697817	0.502039	0.408777	0.983457	0.772698
May	0.430005	0.690494	0.462986	0.237921	0.967131	0.746615
JUNE	0.439848	0.666168	0.419536	0.263707	0.951014	0.841324
JULY	0.276765	0.641423	0.507951	0.302759	0.983443	0.80832
AUG	0.377456	0.697602	0.543404	0.326904	0.951014	0.806362
SEPT	0.361154	0.827414	0.514496	0.321776	0.983463	0.901026
OCT	0.447894	0.904026	0.530169	0.30978	0.967156	0.884527
NOV	0.457971	0.887958	0.627421	0.59144	0.967105	0.919298
DEC	0.579612	0.919036	0.670306	0.385191	1	0.934459

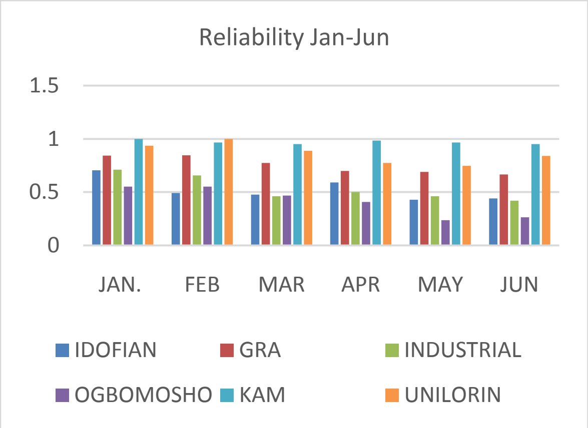

Figure 6(a): Chart of the feeders against months of occurrence (Jan.-Jun.).

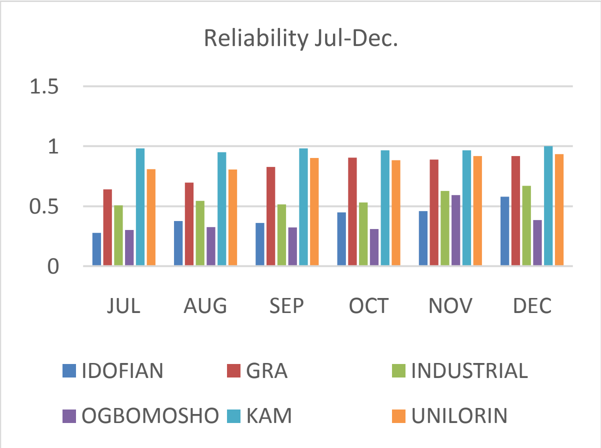

Figure 6(b): Chart of the feeders against months of occurrence (Jul.-Dec.)

Figure 6(a) and 6(b) show the monthly reliability of each feeder. Generally, the customers served by these feeders experience more power outages during the period of May to October which can be attributed to weather condition during this period. Hence, a maintenance culture has to be developed in order to mitigate the power outages during this period.

V. Maintainability of Each Feeder

The necessity to reduce the duration of power outages leads to the study of how possible is it to perform a successful repair action on each feeder and this is known as maintainability. In other words, maintainability measures the ease and speed with which a system can be restored to operational condition after a failure occurred. The maintainability issue is to be achieved within a short repair times for keeping availability high so that downtime of productive equipment is minimized for cost control when availability is critical. Table5 below shows the maintainability of each feeder.

Table5: Average monthly maintainability of each feeder per month

MONTH	IDOFIAN	GRA	INDUSTRIAL	OGBOMMOSHO	KAM	UNILORIN
JAN.	0.959786	0.999916	0.99128	0.99389	1	0.999453
FEB.	0.997422	1	0.999858	0.993369	0.999995	1
MAR	0.957446	0.999795	0.992588	0.988491	0.999998	0.997229
APRIL	0.957603	0.989238	0.977657	0.998162	1	0.913927
MAY	0.983489	0.998288	0.993024	0.98788	0.999997	0.822867
JUNE	0.955668	0.976863	0.983378	0.995204	0.999985	0.991008
JULY	0.967069	0.998833	0.994768	0.993669	0.999937	0.96405
AUG	0.972608	0.988706	0.985711	0.990089	0.999985	0.940851
SEP	0.976001	0.996582	0.991536	0.99489	1	0.915342
OCT	0.966888	0.999987	0.99499	0.997782	1	0.906695
NOV	0.979275	0.998347	0.997882	0.997674	0.999941	0.999823
DEC	0.997539	0.998361	0.999898	0.987454	1	0.98229

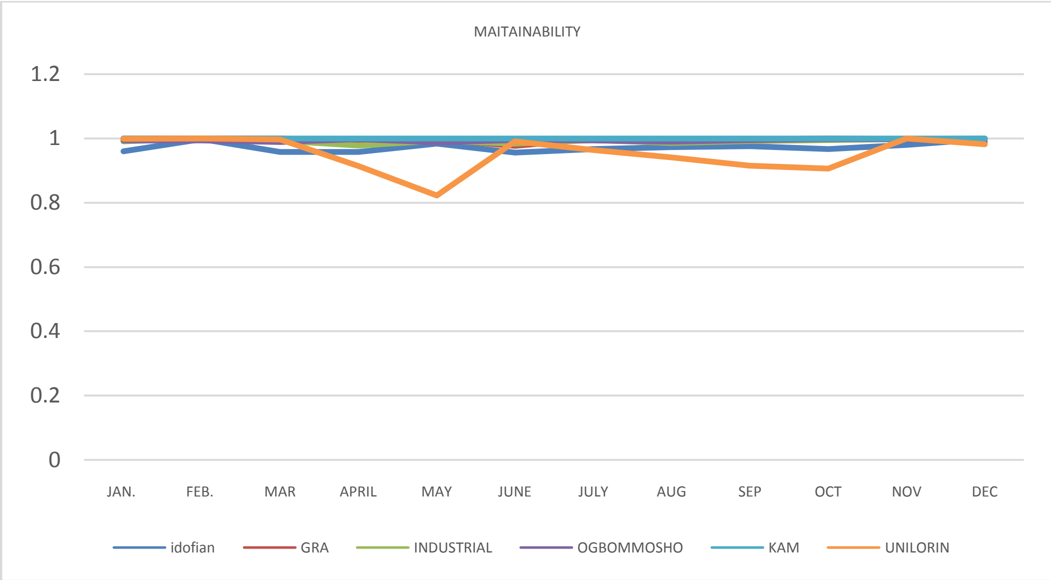

Figure 7: Graph of maintainability of each feeder against month.

Figure 7 represent the maintainability of each feeder. It is understood from the graph that the maintainability of each feeder is almost 100% which means that the feeders can be restored back to operating condition after failure within the computed Mean Time to Repair. However, the probability that the repair will be accomplished within the cap of 24 hours requires control of the following three main items of downtime:

1) Active repair time (a function of design, training, and skill of maintenance personnel),

2) Logistic time (time lost for supplying the replacement parts), and

3) Administrative time (a function of the operational structure of the organization).

VI. Maintenance Strategies

Afterthe assessment of reliability and maintainability of Ganmo 33kv feeders, it becomes necessary to discuss alternative maintenance strategies for the feeders. As discussed above feeders such as KAM and UNILORIN possessed the highest reliability and availability. Thus, they require less attention (in terms of maintenance) compare to others such as; GRA, Idofian, Ogbomosho and Industrial.

An analysis of practical maintenance shows that it is, above all, component-oriented strategies that are used to keep up the operability of operating systems, plants and networks of power distribution networks. In this paragraph, alternative strategies for maintenance are examined with a view to influencing component-related maintenance costs. The term “alternative strategies” covers both improved component-oriented and system oriented strategies. Table6 shows the criteria applies to maintenance measures of different strategies. Reliable assessment of the technical condition of components is not only the prerequisite for implementation condition-based maintenance strategies; it is also the basis for the application of system- and risk-oriented maintenance.

Table6: maintenance measure of different strategies.

Measures / Strategy	Inspection	Servicing	Repair	Renewal
Corrective	-	-	In case of outage	In case of outage
Time-based	According to interval	According to interval	In case of outage	According to interval
Condition-based	Cyclic or continuous(monitoring)	According to condition	In case of outage	According to condition
Reliability-centred	***‘Strategies overall process’ considering the importance of the network component to system reliability.***			
Risk-based (quantification of outage cost)	***Cyclic or continuous(monitoring)***	***According to condition, importance and outage risk***	***In case of outage***	***According to condition, importance and outage risk***

VII. Conclusion

This project presented the reliability evaluation of Ganmo 33KV feeders with maintenance strategies. The outages on the TCN Ganmo 33KV feeders have been studied for 24 months based on daily outage data collected from the station. Based on the result obtained from the data analysis illustrated with graphs, it can be deduced that dedicated feeders such as KAM and UNILORIN have the highest reliability and more available compared to others residential feeders. This can be attributed to the level of their load demands. Generally, the feeders have least reliability during the period of May to October due to high vegetation and rainfall.

The proposed maintenance strategy is that feeders; despite of the same level of voltage should sometimes be maintained on different time interval due to their distance covered, load demand, feeder type (residential or dedicate), and how available and reliable they are. Feeders with low reliability and availability should be maintained more frequently compare to others with higher reliability in order to reduce the failure rate.

VIII. Recommendations

After assessing the reliability of the feeders, it is important to apply the interruption mitigation techniques in order to obtain a better result. Hence it is important to analyse the root causes of fault and apply mitigation techniques. The mitigation techniques can be basically classified into two categories: electric and non-electric. Electric mitigation techniques have a direct impact on the distribution system and affect the distribution system analysis while non electric mitigation techniques do not have any impact on other engineering tools. It is therefore necessary to apply both the techniques in order to obtain better improvement in reliability of the system.

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