MODELING AND ANALYSIS OF POWER OUTAGES IN A 33/11kV DISTRIBUTION SUBSTATION USING FAULT TREE ANALYSIS TECHNIQUE

BY
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ABSTRACT

This research work has performed the modeling and analysis of power outages in a 33/11kV distribution substation using fault tree analysis (FTA) technique. More specifically, the Anglo-Jos distribution substation of the Jos Electricity Distribution PLC was used as the case study for this research. The aim of the research is to analyze the reliability of power equipment in a distribution substation by using fault tree analysis. The data recorded in the substation's log book was used as the field data for this research work. The field data includes frequencies of failures of power equipment in the substation and their respective durations of failures. The field data was analyzed for four years period (2013 -2016). Firstly, the fault tree diagram of the power equipment in the distribution substation was constructed. The FTA model showed the logical arrangement of the basic events in hierarchical form leading to the desired top event. Secondly, the simulation model of the fault tree was done using Matlab-Simulink software. The fault tree Simulink model gave the overall system unavailability of power for each year. The overall system unavailability for each year was compared and the result showed a marginal improvement in system reliability within the period.

Keywords--- Power Outages, Fault Tree Analysis, Distribution Substation and System Unavailability.

INTRODUCTION

The Nigeria power sector operates well below its estimated capacity with power outage being of a frequent occurrence. Power outages have assumed a very high embarrassing dimension in Nigeria. Despite the current generation and supply of about 4,800 MW and on-going projects to add 2000MW of power to the national grid, there has not been any improvement on the quality of service and power outages are still been experienced in most part of the country. More than 90% of Nigerians cannot boast of 16hours of electricity supply daily[1].Power outages occur as a result of failures of systems at the generation, transmission and distribution substations. Power outages can be especially disastrous when it comes to life-support systems in places like hospitals and nursing homes, or in co-ordination facilities such as in airports, train stations, and traffic control[2]. Fault tree analysis can be used as a valuable design tool, can identify potential accidents, and can eliminate costly design changes. It can also be used as a diagnostic tool, predicting the most likely system failure in a system breakdown. FTA is used in safety engineering and in all major fields of engineering [3].

LITERATURE REVIEW

A fault tree is an analytical technique by which conditions and factors that can contribute to a specified undesired event are identified and organized in a logical manner and represented pictorially [4]. FTA is a systematic deductive technique, which allows the development of the causal relations leading to a given undesired event. It is deductive in the sense that it starts from a defined system failure event and unfolds backward its causes, down to the primary (basic) independent faults. The method focuses on single failure mode and can provide quantitative information on how a particular event can occur, to what consequences it leads, while at the same time allowing the identification of those components, which play a major role in determining the defined system failure. Moreover, it can be solved in quantitative terms to provide the probability of events of interest starting from knowledge of the probability of occurrence of the basic events, which cause them [5]. FTA is based on reliability theory, Boolean algebra and probability theory. The modeling structure of FTA allows the modeler to visualize the system architecture in terms of primary component's relational dependency on subcomponents [6]. The biggest advantage of using FTA is that it starts from a top event that is selected by the user for a specific interest and the tree developed will identify the root cause. The FTA has the ability to be used with computer and generate results using computer applications for improved analysis

METHODOLOGY

The daily recording of faults that occurred in the 33/11kV Anglo-Jos distribution substation were recorded in the station's log book. The log books were used as data received. The data for four years (2013 to 2016) were reviewed and various information needed were extracted from the log book. The field data can be seen in Table 1 and Table 2. The duration and frequencies of failures of each power equipment were carefully tabulated. The first step requires the construction of the fault tree. The fault tree is constructed in a hierarchical structure with a single top event. In this research work, the top event is the overall system unavailability.The second step is the modeling of the fault tree using the MATLAB-Simulink software. Once the Simulink model is constructed, top event and basic events are then defined in order to know the basic components that leads to the top events. The tree is then analyzed by using the failure probability (P) or failure-rate (λ) of basic events.

$$failure\ rate\ \lambda = \frac{number\ of\ times\ failure\ occurred}{number\ of\ unit - hours\ of\ operation} \quad \ldots (1)$$

$$MTBF = \frac{Total\ system\ operating\ hrs}{Number\ of\ failures} \quad \ldots (2)$$

$$MTTR = \frac{Total\ duration\ of\ outages}{Freguency\ of\ outage} \quad \ldots (3)$$

$$Availability, A = \frac{MTBF}{MTBF + MTTR} \quad \ldots (4)$$

$$Unavailability = \frac{MTTR}{MTBF + MTTR} = \frac{f \times MTTR}{8760} \quad \ldots (5)$$

Where $R_{(t)}$= Reliability

$Q_{(t)} = Failure\ Probability$

λ = failure rate

T = Average down time per failure

MTBF= Mean Time Between Failure

MTTR = Mean Time to Repair

8760 = Total hours for a year

Table 1: Power Equipment in 33/11kV Anglo-Jos Distribution Substation

S/NO	POWER EQUIPMENT	PIECES
1	33 KV LINE	3
2	150MVA POWER TRANSFORMERS	2
3	AUXILLIARY TRANSFORMER	1
4	110V DC BATTERY BANK	1
5	33KV CIRCUIT BREAKER	6
6	CURRENT TRANSFORMER	6
7	DISC INSULATORS	6
8	11KV FEEDERS	4

Table 2 : Data Received from 33/11kV Anglo-Jos Distribution Substation

S/NO	POWER EQUIPMENT	2013 DATA		2014 DATA		2015 DATA		2016 DATA	
		Freq (F)	Duration (HRS)	Freq (F)	Duration (HRS)	Freq (F)	Duration (HRS)	Freq (F)	Duration (HRS)
1	33 KV LINE	123	211	160	92	43	79	29	70
2	AUXILLIARY TRANSFORMER	18	38	22	41	24	45	22	45
3	110V DC BATTERY BANK	3	45	3	35	3	36	5	36
4	33KV CIRCUIT BREAKER	5	13	6	14	4	12	2	2
5	CURRENT TRANSFORMER	2	2	2	2	2	2	1	1
6	DISC INSULATORS	14	12	15	15	12	12	10	12
7	POWER TRANSFORMER T1	12	49	14	58	12	44	11	40
8	POWER TRANSFORMER T2	4	16	3	10	4	12	3	11
9	11KV LIBERTY DAM FEEDER	175	334	149	79	128	338	86	264
10	11KV HWOLSHE FEEDER	138	195	143	79	70	134	40	84
11	11KV TUDUN WADA FEEDER	134	177	70	54	44	91	48	117
12	11KV IBRAHIM TAIWO FEEDER	113	177	97	66	36	101	53	94

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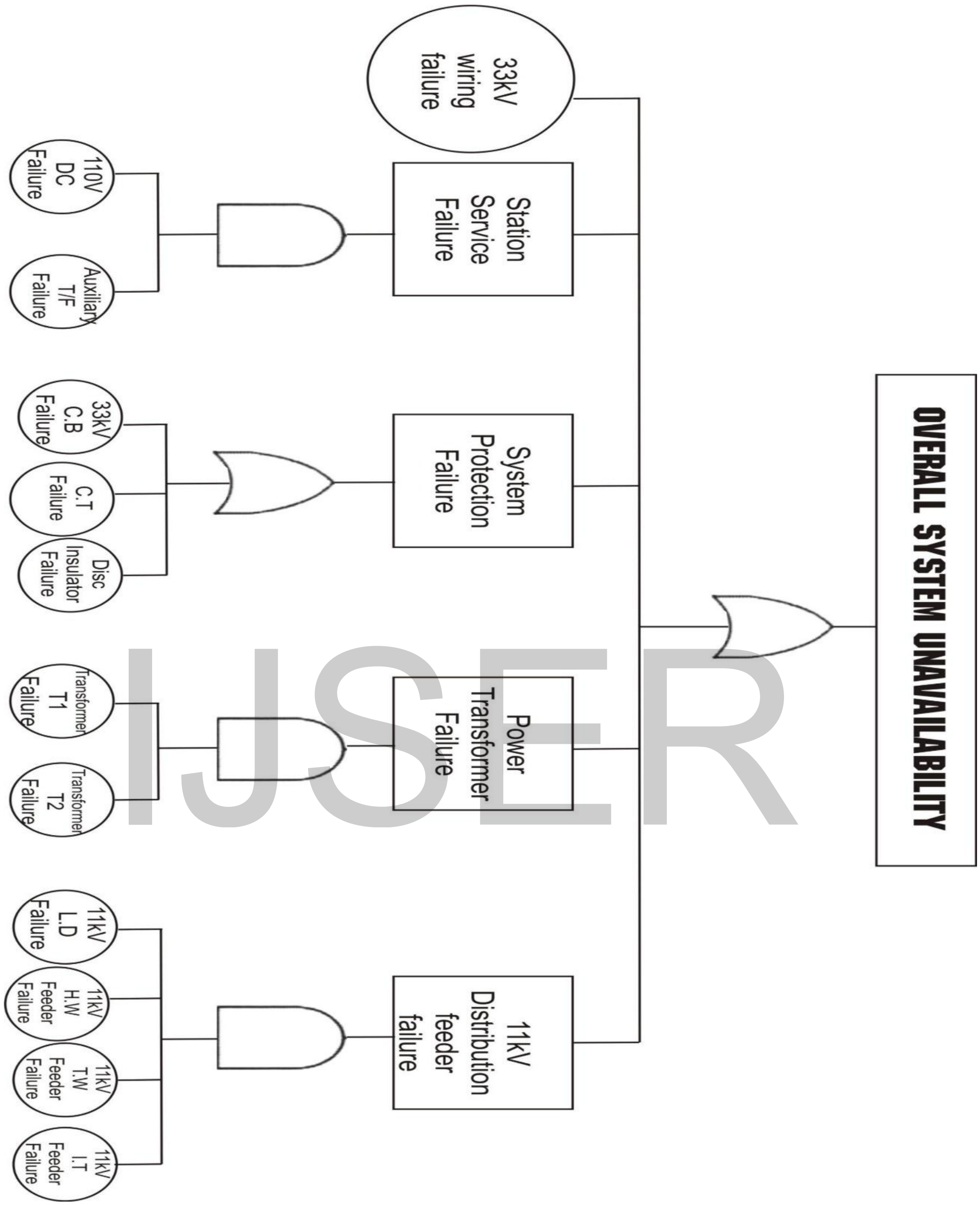

Figure 1: Fault Tree Diagram of the 33/11kV Anglo-Jos Distribution Substation.

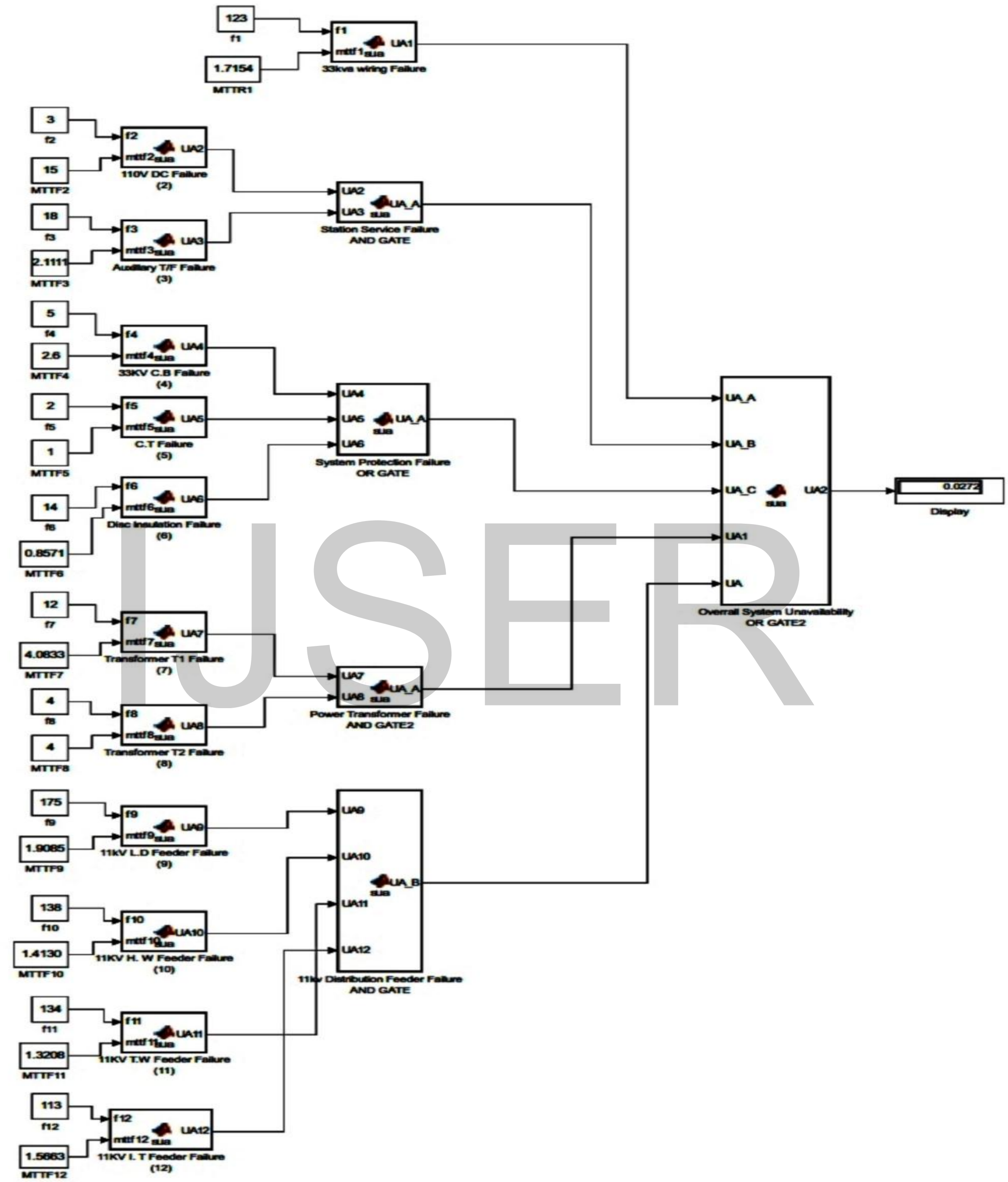

Figure 2: Model and Simulation of the Power Equipment in 33/11kV Anglo-Jos Distribution Substation Using Matlab-Simulink Software

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RESULTS AND DISCUSSIONS

The fault tree diagram of this research work can be seen in Figure 1 and the simulation model can be seen in Figure 2. The simulation results gave the overall system unavailability of the power equipment in the 33/11kV Anglo-Jos distribution substation. The comparison of the overall system unavailability for each year was done as represented in Table 3 and Figure 3. The results show that the year 2013 had the highest overall probability of system unavailability and the year 2016 had the least overall probability of system unavailability. The results also show that there has been a marginal improvement in the probability of the system unavailability between year 2013 and 2016.

Table 3: The overall System Unavailability of Power Equipment in 33/11kV Anglo-Jos Distribution Substation

S/NO	YEAR	OVERALL SYSTEM UNAVAILABILITY 10^{-4}
1	2013	27202
2	2014	14067
3	2015	12014
4	2016	9730

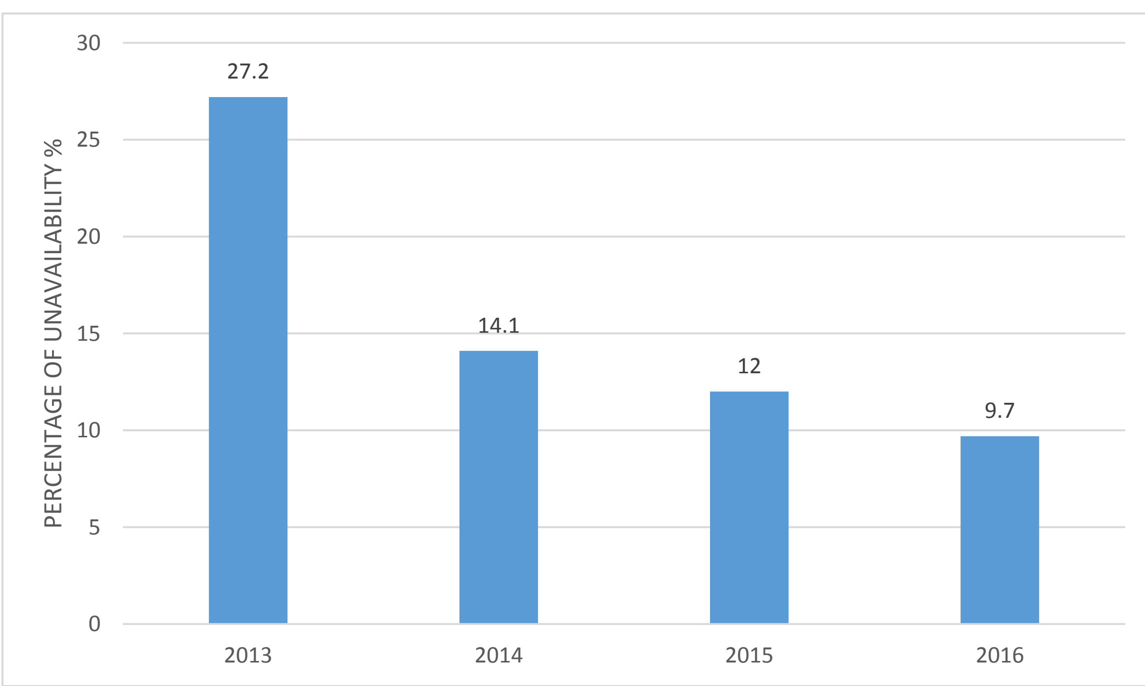

Figure 3: Comparison of the overall system unavailability of the power equipment in 33/11kV Anglo-Jos distribution substation.

CONCLUSION

The aim of this research work is to give a model of analyzing power outages in a 33/11kV distribution substation using fault tree analysis technique. The technique used has provided a method of reliability analysis of the distribution substation. The study has shown the yearly reliability indices of the power equipment in the distribution substation. The simulation model provides a system of analyzing any power distribution substation. The model and the results of this work can be used as an input data for reliability analysis of a transmission and generation substations.

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