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Reliability Assessment of APO 132/33 KV Electric Transmission Substation Abuja

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Abstract: *This study investigate the reliability assessment of Apo 132/33kV Transmission substation, Abuja-Nigeriato provide adequate electrical supply to its customers as economically as possible with reasonable level of reliability. The system reliability impact data on statistical information were classified as unscheduled (forced) and scheduled(planned)maintenance outages on each feeder were collected from January to December, 2015 as documented in the daily logbooks. The data wereused to compute and analyzed the reliability indices using Microsoft and Excel package with respect to customer orientation indices of SAIFI, SAIDI, CAIDI, and ASAI using equations 1 to 4. The results shows thatunscheduled (forced) outages reliability indices for H3, H13 and H15 feeders for average service availability index (ASAI) were 0.9935, 0.9935, and 0.996; while consumer average interruption duration index (CAIDI) were 3.48, 3.7, and 2.368 respectively. The maximum CAIDI was recorded on feeder H13 in the month of October with interruption duration of 3 hours and 42 minutes. The maximum system average interruption duration index (SAIDI),recorded 17.193, 13.49, and 9.875 with the highest in June on feeder H3 and 13 hours 33 minutes. Also the maximum system average interruption frequency index (SAIFI), for the corresponding feeder's were7.6, 6.0, and 5.7 respectively. The results of planned outages system reliability for the same feeders were also analyzed and presented.*

Keywords: *Reliability indices, unscheduled outages, availability index, power system, failure, outage duration.*

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I. INTRODUCTION

Power System Reliability

Reliability indices for distribution systems are used by utilities and regulators to benchmark performance and prioritize investments in projects to improve performance. The basic function of the power system is to provide an adequate electrical supply to its customers as economically as possible with reasonable level of reliability. With growing demand and increasing dependence on electricity supplies, the necessity to achieve an acceptable level of reliability, quality and safety at an economic price, the utility have to evolve and improve the systems continuously depending upon the requirement of the customers. Reliability has to do with the ability of an item to perform a required function, under given conditions, depending on the reliability level that is going to be studied. The two reliability levels are referred to as system and component reliability respectively. From the engineering point of view, a simple definition of reliability is that it is the probability that an item or a collection of items will perform satisfactorily, under specified conditions during a given period[2]. The period assigned is thus an essential part of reliability specification. The period may be the complete lifetime of the item or any permissible period during maintenance. With regards to the system under study, reliability can be described as the function of an electric power system that satisfies the system load requirement with a reasonable assurance of continuity and quality. The ability of the system to provide an adequate supply of electrical energy is usually designated by the term reliability. The concept of power system reliability is extremely broad and covers all aspect of the ability of the system to satisfy the customer requirements. There is reasonable subdivision of the concern designated as ``system reliability`` as shown in figure 1.

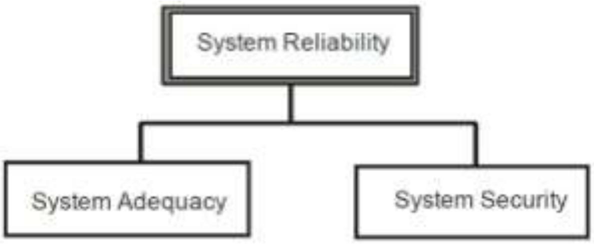

Figure 1 Subdivision of System Reliability

Figure 1 represents two basic aspect of power system: system adequacy and security. Adequacy relates to the existence of sufficient facilities within the system to satisfy the consumer load demand. These include the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities required to transport the energy to the actual customer load points. System security on the other hand is the ability of electric power system to withstand sudden disturbances, such as electric short circuits or unanticipated loss of system elements [1] Transmission reliability primarily relates to equipment outages and customer interruptions. An outage occurs when a piece of equipment is de-energized. Outages can be either planned (scheduled) or Forced (unscheduled). Planned outages are known in advance. Forced outages result from contingencies. In normal operating conditions, all equipment is energized and all customers are energized. Planned and Forced events disrupt normal operating conditions and can lead to outages and interruptions. The forced events are caused either due to human error or due to equipment failures. The planned events are meant for periodic maintenance of the equipment and shall be notified in advance to the customers. Several indicators are used to evaluate reliability in the transmission and distribution system.

II. GENERAL DESCRIPTION

2.1 Reliability Indices

Quantitative reliability evaluation of a transmission and /or distribution system can be divided into two basic segments; measuring of the past performance and predicting the future performance [12].Past performance statistics provide valuable reliability profile of the existing system.

However, distribution planning involves the analysis of future systems and evaluation of system reliability when there are changes in; configuration, operation conditions or in protection schemes. This estimates the future performance of the system based on system topology and failure data of the components. Due to stochastic nature of failure occurrence and outage duration, it is generally based on probabilistic models. Some of the basic indices that have been used to assess the past performance are;

- System Average Interruption Frequency Index (SAIFI)
- System Average Interruption Duration Index (SAIDI)
- Customer Average Interruption Duration Index (CAIDI)
- The Average Service Availability Index (ASAI)

SAIFI indicates how often an average customer is subjected to sustained interruption over a predefine time interval whereas SAIDI indicates the total duration of interruption an average customer is subjected for a predefined time interval. CAIDI indicates the average timerequired to restore the service. ASAI specifies the fraction of time that a customer has received the power during the predefine interval of time.

2.2 Availability

Availability is the probability of something being energized. It is the most basic aspect of reliability and is typically measured in percent or per-unit. The complement of availability is unavailability. Unavailability is defined as the probability of not being energized. It can be computed directly from interruption duration information. If a customer's experiences 9 hours of interrupted power in a year, unavailability is equal to 9 ÷8760 = 0.1% (8760 hours in a year).

Availability is equal to 100% -0.1% = 99.9%. Annual interruption times corresponding to various degrees of availability are shown in Table 1.0.

Table 1.0: Annual interruption times associated with different levels of availability.

Availability (%)	'Nines'	Time
90	1	36.5 days
99	2	3.7 days
99.9	3	8.8 hours
99.99	4	52.6 minutes
99.999	5	5.3 minutes
99.9999	6	31.5 seconds
99.99999	7	3.2 seconds

With the growth of ultrasensitive loads, it has become common to describe high levels of reliability by the number of nines appearing at the left of availability values.

III. MATERIAL AND METHODOLOGY

Apo Transmission substation (AT3) is under Transmission Company of Nigeria (TCN), Abuja sub-region is a 132/33/11kV Substation, having the capacity of 250MVA. Apo transmission station is a work center. The substation is connected to the National grid via Katampe 330/132KV and Kukwaba (Gwagwalada) 330/132KV stations on 2 incoming lines. Apo Transmission Substation is a 132/33kV feeders located in the suburb of Apo, a fast growing town in the Nigerian Federal Capital Territory (FCT) Abuja. The substation comprises of 10 by 33kV and one spare outgoing feeder lines namely: (H37, H35, H33, H31, H3, H7, H11, H13, H15, H21, & H23) as shown in figure 2.

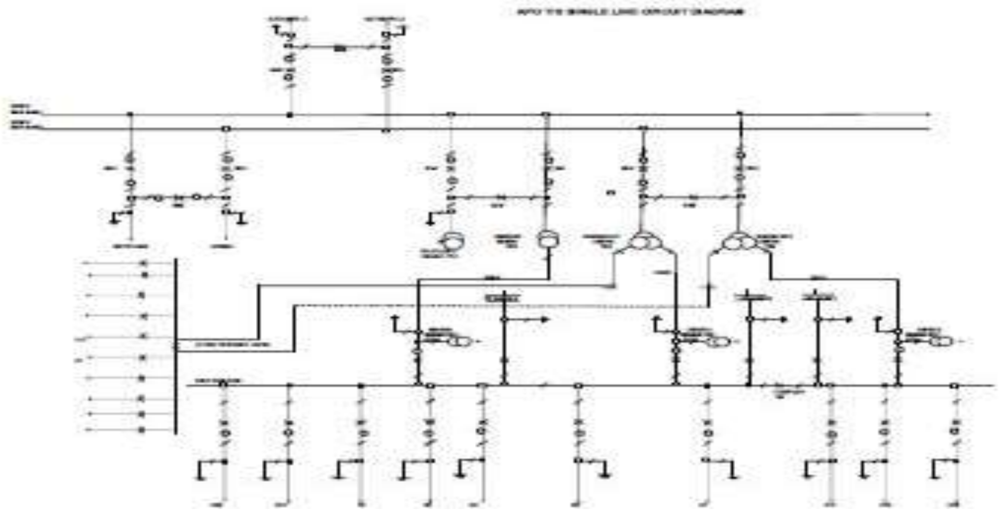

Figure 2: Apo Transmission Station

However, reliability assessment were conducted on three (H3, H13, & H15) of the 33kV feeders. These substations supply highly sensitive customers, including the Presidential Villa, National Assembly Complex, Federal Secretariat, the entire central area (top Government quarters, military formations, airport (local and international), as well as Asokoro to Kuchingoro).

3.1 Reliability Indices

Reliability indices are statistical aggregations of reliability data for a well-defined set of loads, components or customers. Most reliability indices are average values of a particular reliability characteristic for an entire system, operating region, substation service territory, or feeder.

a) Customer Based Indices

The Utilities commonly use the following two reliability indices for frequency and duration to quantify the performance of their systems [3].

1) System Average Interruption Frequency Index (SAIFI) is designed to give information about the average frequency of sustained interruptions per customer over a predefined area. SAIFI is a measure of how many sustained interruptions an average customer will experience over the course of a year.

$$SAIFI = \frac{\text{Total numbers of customers interruption}}{\text{Total numbers of customers served}} = \frac{\sum N_i}{\sum N_T}(/yr) \quad (1)$$

For a fixed number of customers, the only way to improve SAIFI is to reduce the number of sustained interruptions experienced by customers.

2) System Average Interruption Duration Index, (SAIDI) is commonly referred to as customer minutes of interruption or customer hours, and is designed to provide information about the average time that the customers are interrupted. SAIDI is a measure of how many interruption hours an average customer will experience over the course of a year.

$$SAIDI = \frac{\textit{sum of customer interruption duration}}{\textit{Total numbers of customers served}} = \frac{\sum N_i * RI}{\sum N_T}(hr/yr) \quad (2)$$

SAIDI can be improved by reducing the number of interruptions or by reducing the duration of these interruptions. Since both of these reflect reliability improvements, a reduction in SAIDI indicates an improvement in reliability.

3) Customer Average Interruption Duration Index (CAIDI) is the average time needed to restore service to the average customer per sustained interruption: CAIDI is a measure of how long an average interruption lasts, and is used as a measure of utility response time to system contingencies.

$$CAIDI = \frac{sum\ of\ customer\ interruption\ duration}{Total\ numbers\ of\ customers\ interruption} = \frac{\sum N_{i*}R_I}{\sum N_i}(hr) \qquad (3)$$

CAIDI can be improved by reducing the length of interruptions, but can also be reduced by increasing the number of short interruptions.

Average Service Availability Index (ASAI). It is the ratio of the total number of hours the service was available during a given time period to the total customer hours demanded. This is sometimes called service availability index. It is usually calculated in yearly basis (8760 hours).

$$ASAI = \frac{customers\ hours\ of\ available\ service}{customers\ hours\ demanded} = \frac{\sum N_T\ X\ 8760 - \sum N_T\ R_I}{\sum N_T\ x\ 8760}\ x100 \qquad (4)$$

ASAI is the customer-weighted availability of the system and provides the same information as SAIDI

Equations 1 to 4 are expressed accordingly,

Where

N_I = Total number of customers interrupted

R_I = Restoration time or outage duration.

N_T = Total number of customers served.

T = Time period under study in hour.

IV. ANALYSIS

Computation of the reliability indices from January to December,2015shown in tables 2 to 9planned outage annual SAIFI indexto forced outage annual ASAI index were analyzed using equations 1 to 4,whileMicrosoft excel was used togenerate the correspondingcharts presented in figures 3 to 6 planned outage annual SAIFI, SAIDI, CAIDI and ASAI index as well as figures 7to 10 representing forced outage annual SAIFI, SAIDI, CAIDI and ASAI index respectively.

Table 2: Planned Outage Annual SAIFI Index

Months	FEEDERS		
	H3	H13	H15
Jan	3.6	4.5	3.6
Feb	4.4	4.2	3.0
March	2.0	4.5	2.1
April	2.8	3.9	2.7
May	3.6	3.0	1.2
June	4.0	6.0	4.2
July	2.8	3.6	3.6
Aug	3.6	2.7	2.4
Sept	3.2	2.1	2.7
Oct	3.6	1.8	2.4
Nov	2.8	2.1	2.4
Dec	3.6	2.4	2.1

Table 3: Planned Outage Annual SAIDI Index

Months	FEEDERS		
	H3	H13	H15
Jan	4.2867	6.4300	3.9450
Feb	4.4267	4.4400	4.8750
March	6.5067	7.2650	1.8900
April	4.2267	6.7200	4.7800
May	6.5067	6.0000	1.7800
June	6.0400	6.2700	5.0200
July	3.0933	6.2800	4.8350
Aug	3.7800	4.9000	2.8650
Sept	3.3200	5.8200	2.7350
Oct	4.0333	2.7750	4.4650
Nov	3.9400	8.7150	2.8450
Dec	3.5467	2.1800	3.9500

Table 4: Planned Outage Annual CAIDI Index

Months	FEEDERS		
	H3	H13	H15
Jan	1.1907	2.5400	1.0953
Feb	1.0061	1.0571	1.6250
March	3.2533	1.6144	0.9000
April	1.5095	1.7231	1.7704
May	1.8074	2.0000	0.6500
June	1.5100	1.0450	1.1952
July	1.1048	0.6333	1.3431
Aug	1.0500	1.8148	1.1938
Sept	1.0375	2.7714	1.0130
Oct	1.1204	1.5417	1.3530
Nov	1.4071	4.1500	1.1854
Dec	0.9852	0.9083	1.8810

Table 5: Planned Outage Annual ASAI Index

Months	FEEDERS		
	H3	H13	H15
Jan	0.9941	0.9910	0.9945
Feb	0.9939	0.9938	0.9932
March	0.9910	0.9899	0.9974
April	0.9941	0.9907	0.9934
May	0.9910	0.9917	0.9989
June	0.9916	0.9913	0.9930
July	0.9957	0.9968	0.9933
Aug	0.9948	0.9932	0.9960
Sept	0.9954	0.9919	0.9962
Oct	0.9944	0.9961	0.9938
Nov	0.9945	0.9879	0.9960
Dec	0.9951	0.9970	0.9945

Table 6: Forced Outage Annual SAIFI Index

Months	FEEDERS		
	H3	H13	H15
Jan	5.200	3.900	4.200
Feb	2.800	3.900	3.600
March	3.600	4.800	2.700
April	3.200	4.200	3.300
May	2.400	3.600	3.900
June	7.600	6.000	5.100
July	5.600	3.300	5.700
Aug	6.000	3.300	3.900
Sept	2.400	3.600	5.100
Oct	2.800	3.300	2.100
Nov	3.600	4.200	2.100
Dec	4.400	5.400	3.300

Table 7: Forced Outage Annual SAIDI Index

Months	FEEDERS		
	H3	H13	H15
Jan	12.713	5.145	7.815
Feb	5.240	7.280	5.350
March	6.040	7.165	2.875
April	5.753	6.725	7.815
May	4.700	6.215	4.870
June	17.193	13.490	5.320
July	12.420	5.670	9.875
Aug	10.560	4.850	4.340
Sept	8.353	5.115	7.320
Oct	6.353	12.225	4.825
Nov	7.173	5.020	4.425
Dec	7.593	11.890	4.825

Table 8: Forced Outage Annual CAIDI Index

Months	FEEDERS		
	H3	H13	H15
Jan	2.4449	1.3192	1.8607
Feb	1.8714	1.8667	1.4861
March	1.6778	1.4927	1.0648
April	1.7979	1.6012	2.3682
May	1.9583	1.7264	1.2487
June	2.2623	2.2483	1.0431
July	2.2179	1.7182	1.7325
Aug	1.7600	1.4697	1.1128
Sept	3.4806	1.4208	1.4353
Oct	2.2690	3.7045	1.7870
Nov	1.9926	1.1952	2.1071
Dec	1.7258	2.2018	1.4621

Table 9: Forced Outage Annual ASAI Index

Months	FEEDERS		
	H3	H13	H15
Jan	0.9823	0.9928	0.9891
Feb	0.9927	0.9899	0.9926
March	0.9916	0.9900	0.9960
April	0.9920	0.9907	0.9891
May	0.9935	0.9914	0.9932
June	0.9761	0.9813	0.9926
July	0.9827	0.9921	0.9863
Aug	0.9853	0.9933	0.9940
Sept	0.9884	0.9929	0.9898
Oct	0.9912	0.9830	0.9933
Nov	0.9900	0.9931	0.9938
Dec	0.9894	0.9849	0.9933

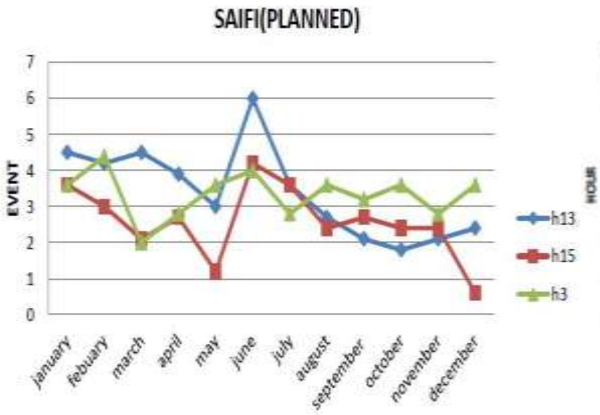

Figure 3: Planned Outage Annual SAIFI Index

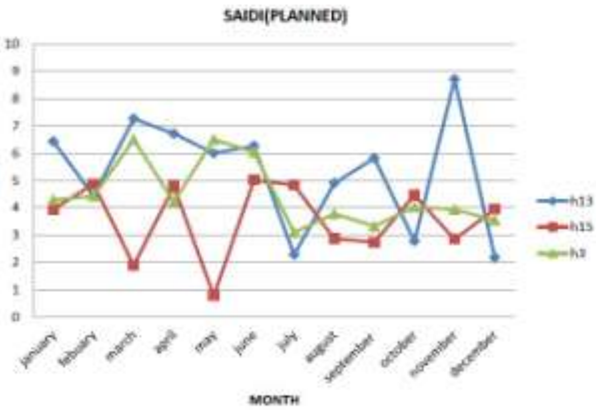

Figure 4: Planned Outage Annual SAIDI Index

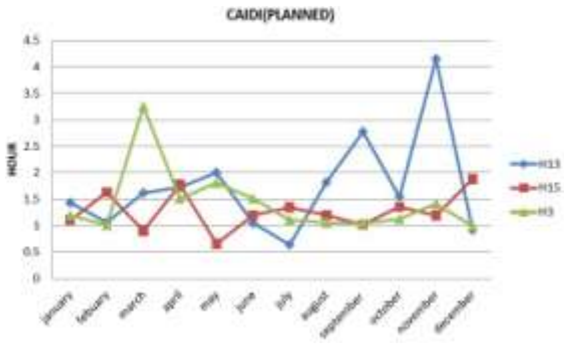

Figure 5: Planned Outage Annual CAIDI Index

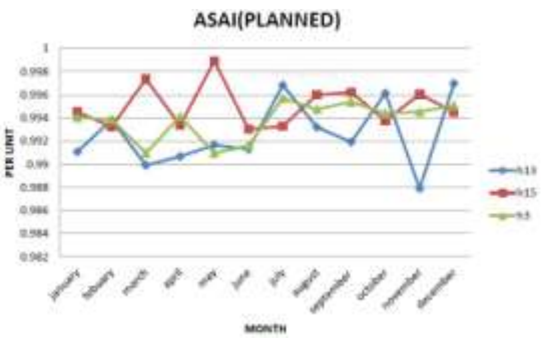

Figure 6: Planned Outage Annual ASAI Index

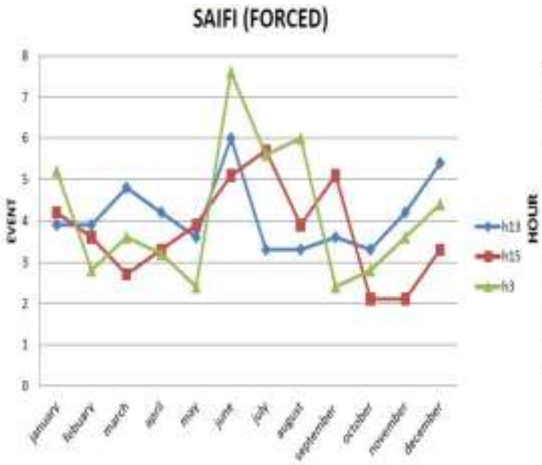

Figure 7: Forced Outage Annual SAIFI Index

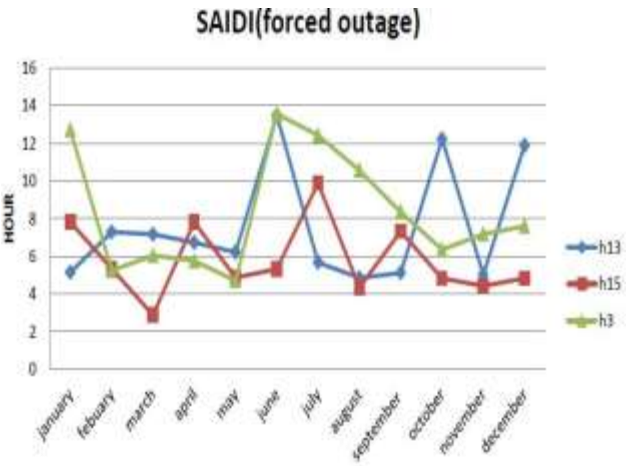

Figure 8: Forced Outage Annual SAIDI Index

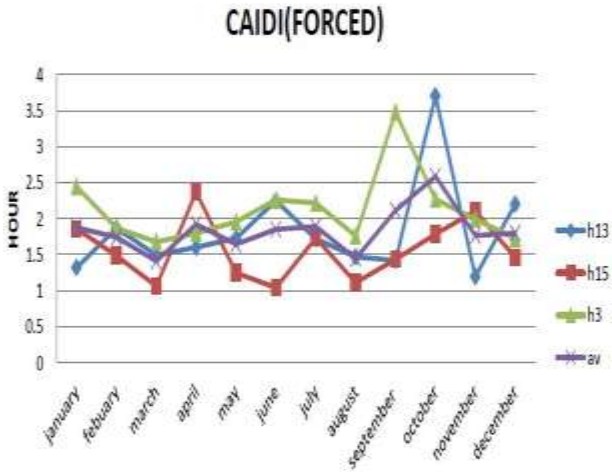

Figure 9: Forced Outage Annual CAIDI Index

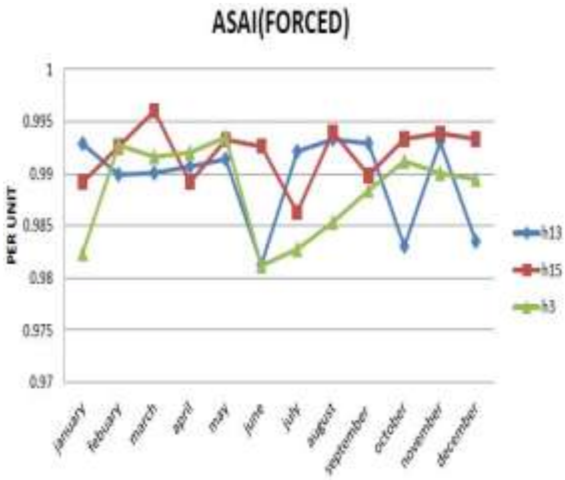

Figure 10: Forced Outage Annual ASAI Index

V. CONCLUSIONS

This paper has analyzed the importance of distribution performance reliability for H3, H13 and H15 feeders.The study shown that circuit configuration has an impact on system reliability.Reliability indices for the three feeders hashigh level of reliability due to geographical location and esteem customers served by these feeders. The network systems provide level of service reliability that are better than any standard distribution configuration in the region.The basic function of the power system is to provide an adequate electrical supply to its customers as economically as possible. With growing demand and increasing dependence on electricity supplies, the necessity to achieve an acceptable level of reliability, quality and safety at an economic price, the utility have evolve and improve on the systems reliability to meet continuously customers requirement.

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