

THE EFFECTS OF AGEING TRANSFORMERS ON IBEDC ELECTRICAL POWER SYSTEM RELIABILITY

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Abstract, Electrical Power System is expected to provide energy continuously and reliably, twenty four hours a day. This calls for high level of reliability of its component parts and operation. To ascertain that an electrical power system maintains an acceptable reliability level, reliability assessment is expected to be carried out on it at regular intervals; hence this work investigates the performance of some old Transformers of Ibadan Electricity Distribution Company using availability as the index of system reliability. The historical data as regards the operational and maintenance performance of the transformers was gathered over a length of time and the data collected was tailored towards the calculation of the component's availability and values obtained were then plotted as the variation of the availability against the years. It was discovered that the system availability of Transformers decreased from close to the standard value of between 0.9950 and 0.9999 to as low as 0.9050 over a period of ten (10) years. As for Dugbe and Molete business units, 50% of their transformers are very old while there is a poor maintenance policy in Ojoo business unit. This is an indication that the old equipment breaks down very often and that the utility should adopt more effective maintenance policy to reduce the system down time. If not, the findings show that in the next decade most of the assets (transformers) of the utility would enter their wear out period and will be due for replacement with huge financial and technical commitments.

Key Words: Ageing, Availability, Transformer, Equipment, Reliability

1.0 INTRODUCTION

Equipment ageing is an undeniable reality in the life power systems. Many companies around the world have a lot of equipment called aged, due to bad performance and increasing failure rate. The failures and outages of these equipment are higher than the acceptable level and have direct effect on the operating and maintenance cost of the power systems. Thus, evaluating the effect of equipment ageing is of great importance in the power system reliability assessment. In reliability concept, evaluation of a complete power system (comprising Generation, Transmission and Distribution Subsystems) as a unit is neither recommended nor is it practically useful, this used to be carried out by investigating the reliabilities of its different stages or subsystems.

As the equipment continues to age and gradually deteriorates, the probability of service interruption due to component failure increases (Raviraj, et al). To ensure adequate revenues generation, maintaining healthy equipment in service at any instance is of utmost importance to the industry (Oladejo, I.O). Thus, an effective maintenance strategy (dictated by the facility age) is essential to deliver reliable electrical power to consumers economically. This goal can be achieved by thorough evaluation of the reliability of ageing power equipment

Reliability of Transformer is very crucial in energy system operation, heavily used power transformer may age and deteriorate at a faster rate than ones not used very often (Haifeng, Ge). Since they are electrically stressed devices, they are tested for both mechanical and electrical performance and for signs of deterioration.

However, reliability engineering with regard to distribution systems involves gathering outage data and evaluating system designs. To increase reliability, it is necessary to understand the causes of outages and types of equipment failures. Ageing management and equipment lifecycle optimization are two techniques that are employed nowadays to obtain optimum equipment utilization and the specific approaches to ageing infrastructure are different for each utility.

On this platform, Ghiani, et al developed a technique for the evaluation of the distribution system reliability based on a sequential Monte Carlo (SMC) simulation which takes into account the role of equipment ageing. In the paper, the attention of the authors was devoted to the modelling of the behaviour of the network components due to ageing. Many of the elements of the networks (e.g switch gears, isolators, etc) considered by the authors have been in service for more than 30-40years and they have begun to exhibit non-constant failure rates that are typical of ageing. The authors were able to show that Cumulative Minute Loss, CML increases with age of equipment.

The work of Nitoi and Pavelescu was based on modelling ageing at the level of electrical systems. They affirmed that the effect of age related degradation of plant components, systems and structures are necessary to be assessed in order for the continuous safe operation of nuclear power plants. They found that the ageing process is an ongoing process; its evolution depends on many factors and can lead to reduced components efficiency if it is left unmitigated. Li also asserted that the British Columbia Transmission Corporation (BCTC) has developed ageing

failure models for power system components and incorporated the models into the system reliability evaluation, based on either normal or Weibull distribution to predict unavailability of a component due to ageing failure in any specified period.

METHODOLOGY

In order to assess the impacts of ageing effect on Transformers' reliability, the historical data as regards the operational and maintenance performance of the concerned equipment for Ibadan Electricity Distribution Company (IBEDC) was gathered over a reasonable length of time. Vital equipment in the distribution system identified to be studied was transformer, this power component determined, to a great extent, the performance of a distribution system (Adebayo et al). Since availability is a very important reliability index that incorporates both failure rates, reliability and maintainability, the data gathered was tailored towards facilitating the calculation of the components' availability. The investigation involved personal interview and consultation of the management and field staff of the three Business Units (BU) of IBEDC selected for the case study. Collection of data for analysis involved:

Consultation of daily logbook in the distribution network of stations of the BU, to assess the overall performance of the transformers over the years

Consultation of monthly faults recorded in the concerned distribution network and recording of information obtained on a data sheet/request form.

Personal interaction with competent/field staff of the distribution network so as to know the rating and age of the transformers.

Physical inspection of transformers in the distribution network to validate the information gathered

For each business unit, ten different locations were considered for each of the identified transformers. The p.a. data on the number of faults (M), total fault duration (D) and total maintenance operation time (E) were gathered for a period of ten (10) years, starting from year 2007 to 2016. (Tables 1, 2, and 3)

To project the availability results for these power components, Haifeng model was adopted which states that Mean Outage Duration r , or Mean Time to Repair (MTTR) r

$$r = \frac{\sum_{i=1}^M D_i}{M} \quad (1)$$

Where D_i (hour) is the outage time for each outages (total fault duration); M is the number of outage events (number of faults) in the time span considered. Conceptually an outage frequency is different from a failure rate but their values are only very close, if the average repair time is very short compared to operating time, it can be seen that availability, average outage duration and outage frequency are related mathematically as expressed below, MTTR:

$$r = \frac{1 - A}{f} \quad (2)$$

f is system failure frequency in a steady-state and Since M represent Number of fault (or outage) p.a, outage frequency (or fault frequency),

$$f = M/\text{year} = \frac{M}{365 \times 24} = \frac{M}{8760}$$

Thus,

$$f = \frac{M}{8760} \text{ /hr} \quad (3)$$

From equation (1),

$$r = MTTR = \frac{\sum_{i=1}^M D_i}{M} \quad (4)$$

Then,

$$A = 1 - rf, \quad (5) \quad A = 1 - \frac{\sum_{i=1}^M D_i}{8760} \quad (6)$$

Using equation 5, the corresponding values of **A** were obtained for the study period of ten (10) years and the values of **E** give the estimates of the time lag between the occurrence of faults and the system restoration into service as depicted in tables 1,2 and 3. **MATLAB** was use to plot the variation of the reliability indices against years (figures 1, 2 and 3).

Table 1: Table of Fault Data and Availability for the Transformers in Ojoo Business

Location	Component Ratings	Age as @ 2012 (yrs)	Operating Years	No. of Faults p. a. (M)	Total Annual Fault Duration, D (hrs)	Total Annual Maintenance Operation Time E (hrs)	Availability $A = 1 - \frac{D}{8760}$
1	4MW, 11kV, 47.2km	22	2007	12	5	3	0.9994
			2008	15	7	5	0.9992
			2009	17	8	6	0.9991
			2010	15	6	4	0.9993
			2011	19	10	7	0.9989
			2012	25	13	9	0.9985
			2013	30	15	10	0.9983
			2014	33	20	16	0.9977
			2015	45	22	17	0.9975
			2016	48	25	19	0.9971
2	2MW 33kV, 3.0km	32	2007	15	6	4	0.9993
			2008	20	7	5	0.9992
			2009	25	9	6	0.9990
			2010	30	11	9	0.9987
			2011	27	13	11	0.9985
			2012	35	20	15	0.9977
			2013	46	24	16	0.9973
			2014	55	30	28	0.9966
			2015	60	38	30	0.9957
			2016	72	42	35	0.9952
3	4.5MW, 11kV, 15.0km	27	2007	20	9	6	0.9990
			2008	24	10	7	0.9989
			2009	30	12	9	0.9986
			2010	35	13	11	0.9985
			2011	42	14	13	0.9984
			2012	50	16	13	0.9982
			2013	58	18	15	0.9979
			2014	68	21	18	0.9976
			2015	75	25	20	0.9971
			2016	80	30	25	0.9966
4	5MW, 11kV, 12.0km	22	2007	29	7	5	0.9992
			2008	30	7	6	0.9992
			2009	35	9	7	0.9990
			2010	40	10	8	0.9989
			2011	47	9	6	0.9990
			2012	55	11	8	0.9987
			2013	60	13	10	0.9985
			2014	68	21	18	0.9976
			2015	72	23	19	0.9973
			2016	77	25	21	0.9971
5	2MW, 33kV, 87.0km	33	2007	13	6	5	0.9993
			2008	14	7	6	0.9992
			2009	15	8	7	0.9991
			2010	16	10	8	0.9989
			2011	17	11	10	0.9987
			2012	20	16	13	0.9981
			2013	18	13	11	0.9985
			2014	23	18	14	0.9979
			2015	25	20	16	0.9977

			2016	27	22	18	0.9975
6	5MW, 33kV, 52.0km	25	2007	30	7	6	0.9992
			2008	32	8	7	0.9991
			2009	35	9	7	0.9990
			2010	37	10	8	0.9989
			2011	38	11	9	0.9987
			2012	40	13	11	0.9985
			2013	40	14	10	0.9984
			2014	42	15	13	0.9983
			2015	47	16	14	0.9982
			2016	50	18	16	0.9979
7	3MW, 33kV, 87.0km	32	2007	32	7	6	0.9992
			2008	34	8	7	0.9991
			2009	35	9	8	0.9990
			2010	39	11	10	0.9989
			2011	42	13	10	0.9985
			2012	44	14	12	0.9984
			2013	47	16	14	0.9982
			2014	47	15	14	0.9983
			2015	50	18	16	0.9979
			2016	52	21	19	0.9976
8	4.5MW, 11kV, 42.6km	22	2007	30	7	4	0.9992
			2008	32	7	5	0.9992
			2009	33	9	6	0.9990
			2010	35	10	6	0.9989
			2011	37	10	7	0.9989
			2012	40	11	8	0.9987
			2013	42	11	9	0.9987
			2014	43	13	10	0.9985
			2015	47	14	11	0.9984
			2016	49	15	12	0.9983
9	4MW, 11kV, 45.3km	29	2007	31	6	4	0.9993
			2008	33	7	5	0.9992
			2009	35	6	5	0.9993
			2010	37	7	6	0.9992
			2011	39	9	7	0.9990
			2012	40	10	8	0.9989
			2013	42	12	9	0.9986
			2014	43	13	10	0.9985
			2015	45	15	13	0.9983
			2016	47	17	15	0.9980
10	3.5MW, 11kV, 38.4km	32	2007	35	7	5	0.9992
			2008	38	7	3	0.9992
			2009	41	8	4	0.9991
			2010	39	6	4	0.9993
			2011	50	9	6	0.9990
			2012	55	10	7	0.9989
			2013	60	12	8	0.9986
			2014	65	14	9	0.9984
			2015	68	14	10	0.9984
			2016	70	15	11	0.9983

Table 2: Table of Fault Data and Availability for Transformers in Dugbe Business Unit

Location	Component Ratings	Age as @ 2012 (yrs)	Operating Years	No. of Faults p. a. (M)	Total Annual Fault Duration, D (hrs)	Total Annual Maintenance Operation Time E (hrs)	Availability $A = 1 - \frac{D}{8760}$
1	15MW, 11kV, 1.2km	28	2007	46	896	6	0.8977
			2008	49	901	10	0.8971
			2009	51	960	12	0.8904
			2010	51	1022	7	0.8833
			2011	53	1066	9	0.8783
			2012	51	1055	12	0.8796
			2013	62	1088	10	0.8758
			2014	62	1149	11	0.8688
			2015	66	1321	13	0.8492
2	6MW, 33kV, 0.55km	33	2007	15	38	6	0.9957
			2008	17	39	7	0.9955
			2009	19	49	4	0.9944
			2010	19	54	10	0.9938
			2011	21	55	7	0.9937
			2012	21	39	10	0.9955
			2013	23	49	10	0.9944
			2014	22	57	6	0.9935
			2015	23	49	5	0.9944
3	7.5MW, 11kV, 0.801km	22	2007	32	106	8	0.9879
			2008	38	106	10	0.9879
			2009	40	109	9	0.9876
			2010	41	113	9	0.9871
			2011	46	117	10	0.9866
			2012	50	119	11	0.9864
			2013	51	122	11	0.9861
			2014	55	128	13	0.9854
			2015	55	133	14	0.9848
4	15MW, 11kV, 3.5km	29	2007	35	420	12	0.9521
			2008	33	385	10	0.9561
			2009	41	491	21	0.9439
			2010	45	530	25	0.9395
			2011	49	575	32	0.9344
			2012	51	615	38	0.9298
			2013	52	715	41	0.9184
			2014	60	815	59	0.9070
			2015	55	720	46	0.9178
5	15MW, 11kV, 3.8km	28	2007	25	280	61	0.9680
			2008	18	220	48	0.9749
			2009	30	350	52	0.9600
			2010	41	490	60	0.9441
			2011	35	313	35	0.9643
			2012	48	510	74	0.9418
			2013	50	614	81	0.9299
			2014	52	625	93	0.9287
			2015	65	705	105	0.9195
6	4.5MW, 11kV, 6.0km	25	2007	25	210	15	0.9760
			2008	35	365	20	0.9583
			2009	40	402	35	0.9541
			2010	41	481	45	0.9451

			2011	44	513	60	0.9414
			2012	39	545	78	0.9378
			2013	45	575	96	0.9344
			2014	50	605	120	0.9309
			2015	51	660	135	0.9247
			2016	62	720	145	0.9178
7	2.5MW, 11kV, 2.0km	27	2007	30	210	30	0.9760
			2008	20	180	15	0.9795
			2009	25	250	21	0.9715
			2010	38	315	50	0.9640
			2011	48	404	60	0.9539
			2012	49	445	75	0.9492
			2013	55	514	81	0.9413
			2014	57	560	97	0.9361
			2015	62	702	165	0.9199
			2016	60	683	120	0.9220
8	4.0MW, 11kV, 0.85km	32	2007	25	350	60	0.9600
			2008	30	380	55	0.9566
			2009	38	410	70	0.9532
			2010	40	412	82	0.9530
			2011	40	480	91	0.9452
			2012	48	510	100	0.9418
			2013	45	520	121	0.9406
			2014	52	555	142	0.9366
			2015	55	610	85	0.9304
			2016	60	718	120	0.9180
9	4.0MW, 33kV, 5.0km	29	2007	22	210	36	0.9760
			2008	30	250	25	0.9715
			2009	45	280	52	0.9680
			2010	35	320	65	0.9635
			2011	48	410	72	0.9532
			2012	50	493	85	0.9437
			2013	55	515	96	0.9412
			2014	60	525	105	0.9401
			2015	65	612	121	0.9301
			2016	68	630	130	0.9281
10	2.0MW, 11kV, 1.5km	27	2007	18	300	15	0.9657
			2008	27	415	25	0.9526
			2009	40	495	38	0.9535
			2010	30	419	28	0.9522
			2011	39	420	45	0.9521
			2012	40	512	52	0.9416
			2013	42	515	61	0.9412
			2014	45	650	73	0.9258
			2015	50	690	81	0.9212
			2016	58	720	92	0.9178

Table 3: Table of Fault Data and Availability for Transformers in Molete Business Unit

Location	Component Ratings	Age as @ 2012 (yrs)	Operating Years	No, of Faults p. a. (M)	Total Annual Fault Duration, D (hrs)	Total Annual Maintenance Operation Time E (hrs)	Availability $A = 1 - \frac{D}{8760}$
1	2×12MW 33kV, 7.4km	28	2007	35	40	10	0.9954
			2008	43	45	15	0.9950
			2009	40	58	21	0.9934
			2010	45	108	25	0.9877

			2011	24	63	30	0.9928
			2012	29	91	34	0.9896
			2013	62	168	45	0.9808
			2014	92	201	68	0.9771
			2015	104	290	75	0.9669
			2016	206	316	87	0.9639
2	7.5MW, 11kV, 11.6km	22	2007	171	73	28	0.9917
			2008	180	82	38	0.9906
			2009	165	91	45	0.9896
			2010	240	101	50	0.9885
			2011	298	117	57	0.9866
			2012	326	118	79	0.9865
			2013	412	310	96	0.9646
			2014	411	218	97	0.9751
			2015	420	319	103	0.9636
			2016	513	339	219	0.9613
3	12MW, 11kV, 4.8km	16	2007	148	58	48	0.9934
			2008	169	67	60	0.9924
			2009	152	91	79	0.9896
			2010	187	96	86	0.9890
			2011	199	101	93	0.9885
			2012	211	103	97	0.9882
			2013	217	112	99	0.9872
			2014	288	117	108	0.9866
			2015	313	127	113	0.9855
			2016	341	213	126	0.9757
4	10MW, 11kV, 5.5km	23	2007	75	48	35	0.9945
			2008	85	53	38	0.9939
			2009	97	62	47	0.9929
			2010	101	71	51	0.9919
			2011	113	83	57	0.9905
			2012	217	103	77	0.9882
			2013	216	98	69	0.9888
			2014	219	110	93	0.9874
			2015	293	130	99	0.9852
			2016	317	239	114	0.9727
5	12MW, 11kV, 48km	25	2007	73	285	50	0.9675
			2008	82	306	56	0.9651
			2009	90	355	65	0.9595
			2010	120	374	74	0.9573
			2011	98	190	29	0.9783
			2012	105	298	40	0.9660
			2013	112	341	44	0.9611
			2014	118	341	62	0.9611
			2015	121	446	96	0.9491
			2016	171	541	116	0.9382
6	12MW, 11kV, 28.km	25	2007	48	140	18	0.9840
			2008	52	158	20	0.9820
			2009	61	165	24	0.9812
			2010	69	180	28	0.9795
			2011	79	211	36	0.9759
			2012	88	304	64	0.9653
			2013	82	291	42	0.9668
			2014	94	321	69	0.9634
			2015	114	345	72	0.9606

			2016	201	369	72	0.9579
7	12MW, 11kV, 6.4km	23	2007	56	182	60	0.9792
			2008	69	201	75	0.9771
			2009	75	220	82	0.9749
			2010	96	341	90	0.9611
			2011	81	226	80	0.9742
			2012	92	240	89	0.9726
			2013	99	411	92	0.9531
			2014	99	429	102	0.9510
			2015	104	541	106	0.9382
			2016	112	610	120	0.9304
8	2×12MW, 33kV, 20.6km	21	2007	70	175	5	0.9800
			2008	86	186	6	0.9788
			2009	95	192	6	0.9781
			2010	100	208	10	0.9763
			2011	52	108	8	0.9877
			2012	69	117	8	0.9866
			2013	84	164	8	0.9813
			2014	101	315	11	0.9640
			2015	115	404	10	0.9539
			2016	120	516	14	0.9411
9	2×12MW, 33kV, 5.2km	21	2007	12	21	2	0.9976
			2008	15	22	3	0.9975
			2009	18	25	4	0.9971
			2010	18	26	4	0.9970
			2011	20	26	5	0.9970
			2012	20	28	6	0.9968
			2013	21	30	5	0.9966
			2014	21	39	4	0.9955
			2015	20	28	4	0.9968
			2016	24	38	6	0.9957
10	12MW, 11kV, 41.0km	20	2007	145	250	8	0.9715
			2008	160	276	10	0.9685
			2009	185	285	10	0.9675
			2010	194	320	11	0.9635
			2011	312	464	10	0.9470
			2012	394	496	11	0.9434
			2013	464	584	12	0.9333
			2014	556	746	26	0.9148
			2015	504	621	20	0.9291
			2016	641	994	40	0.8865

Result of Data Analysis and Discussion

Components Age Distribution: As regards the age distribution of components identified for the study in all the business units investigated, Ojoo Business Unit; Transformer has a life span of 20 – 40 years. In this business unit, 45 to 60% of them are old and are approaching the end of their life span, Though their availability values are very high(approaching the standard value) at the beginning of the study period , they also experienced slight decrease towards the end of the period (fig 1)

These could be attributed to overloading, ageing, and excessive sagging that could lead to phase-phase fault during normal operation. Typical value of availability decreased from 0.9994 at the beginning of the period to

0.9991 at the end of the period. Coupled with their old age, high fault frequencies were observed and therefore improved maintenance policy is advisable before finally replacing the component with new ones.

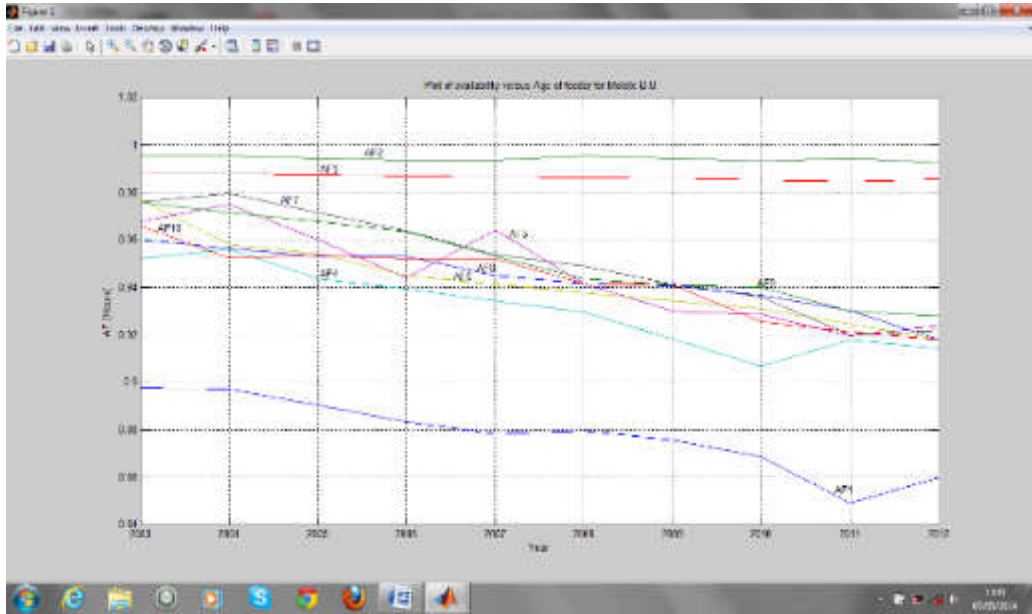


Fig.1: Graph of Availability/ Age for Transformers in Ojoo (Ojoo acg)

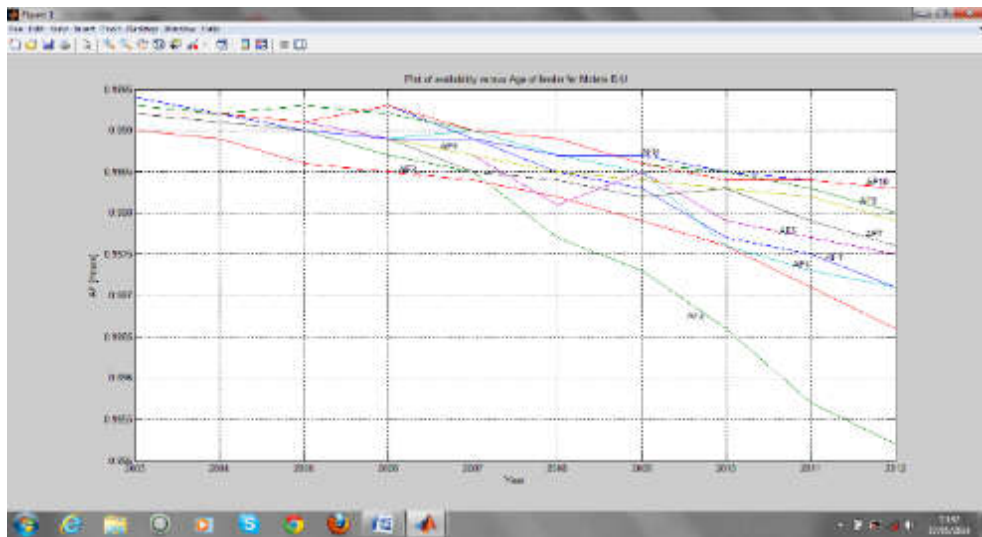


Fig. 2 Graph of Availability/ Age for Transformers in Dugbe (Dugbe acg) Business Unit

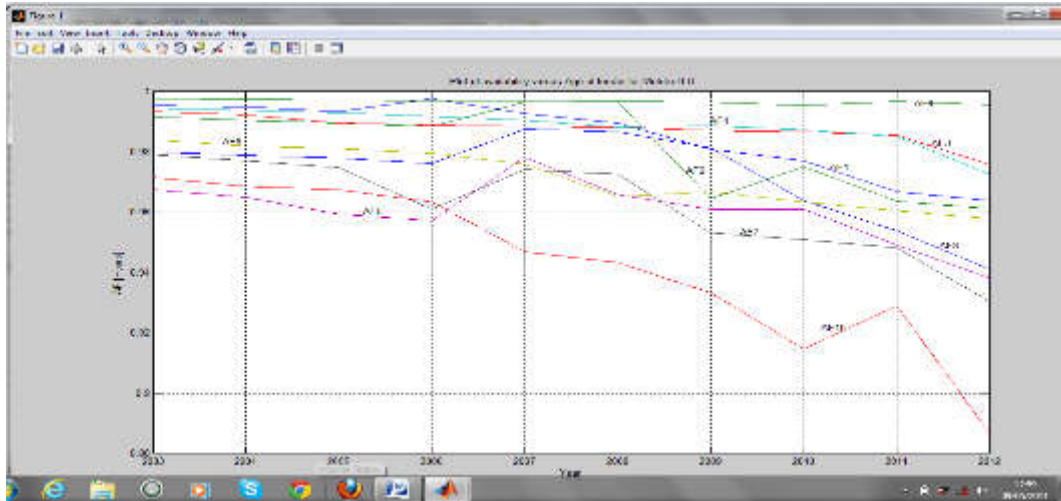


Fig. 3: Graph of Availability versus Age for Transformers in Molete Business Unit (Moleteacg)

Generally for the business units investigated and all the transformers studied, similar pattern of variation of reliability indices over the study period was observed. That is, as the transformers aged;
The number of faults p. a. (M) grossly increased,
The fault duration p. a. (D) correspondingly increased,
The component Availability (A) decreased from close to standard value of between 0.9950 and 0.9999 to a typical value as low as 0.9050 in some cases.(fig 1,2 and 3)

Sequel to information obtained from the analysis of data, the following discussion could be made on component by component basis. On the average, 32 to 58% of the transformers studied are within the range of 10 – 19 years old. This implies that many of these components are in their middle age.

However, chronological age and the frequency of operation (fault interruption) adversely affect the system. For transformers, typical Availability values decreased from 0.9989 to 0.9950 at the beginning and the end of the study period respectively. From the foregoing, it could be seen that the proportion of fairly old and/or old components in the distribution system of the case study is quite high. This partly explains the poor performance of system of the case study. This implies that immediate or nearest future replacement of old equipment is imminent. The replacements could be phased over the remaining useful life of the equipment to cushion the huge financial and technical requirements. More so, adoption of effective maintenance policy such as Condition Based Maintenance (CBM) and Reliability Centred Maintenance (RCM) can also prolong the service life of equipment. Generally, the graph of Availability versus Age shows a decreasing pattern over the years or age, which means it is convex

There are some spikes in the graphs. That is, some increases from low values to higher values. The spikes resulted from maintenance activities carried out on the concerned power transformer at some points in the life of the equipment. When the spike is appreciable, it is as a result of extensive maintenance or refurbishment carried out on the concerned transformer. The reverse case could be experienced when maintenance is not carried out on the equipments as at when due.

4.0 Conclusion and Recommendations

This paper provides insight into the effect of ageing transformers on electrical power distribution system reliability, using Ibadan Electricity Distribution Company (IBEDC) business units as case study. Our study revealed that many of the utility's power transformers are old and some will approach the end of their useful life period in the next decade. Besides, the study revealed that as the equipment aged, reliability indices such Availability is adversely affected, decreasing from close to standard value between 0.9950 and 0.9999 to very low values for all the three business units investigated. This is a clear indication of poor maintenance policy on the part of the utility.

As the results obtained show impending total failure of the transformers, it is recommended that effective maintenance policy should be employed to achieve good system reliability. Maintenance policies such as Condition Based Maintenance (CBM) and Reliability Centred Maintenance (RCM) are thereby suggested, while to cushion the huge financial and technical requirements involved in replacing very old equipment, a phased replacement policy (in which replacement of very old equipment are prioritized) is also recommended.

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