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Evaluation of Akure 132kV Transformer Substation Load Growth Trend.

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A B S T R A C T

Statistical method of the least squares was used in long term load growth forecast based on retrospective load growth data (2003-2023) for Akure 132kV Injection substation. Growth trend was established and the smoothening of the actual growth dynamics was achieved by applying moving averages. The load growth trend line equations obtained enable the determination of load forecast estimate up to 2023. It was inferred from the results that the load growth forecast estimate for transformers, T1A, T2A, T3A and FUTA line are 19.24MW, 28.02MW, 45.02MW and 1.05MW respectively for a period of ten years.

1. Introduction

Akure 132kV Injection substation was commissioned by the defunct Electricity Corporation of Nigeria; ECN which later transformed to National Electric Power Authority, NEPA and Power Holding Company of Nigeria, PHCN which is now unbundled into Generation Companies (GENCOS), Transmission Company (TRANSYCO) and Distribution Companies (DISCOS). GENCOS and DISCOS are privatized while TRANSYCO is still in the hand of the government of Nigeria and is called Transmission Company of Nigeria (TCN). Akure 132kV Transformer Substation – the case study, is under TCN. The substation receives supply from Osogbo 330/132kV circuit and covers about 93km route from Osogbo to Akure on 132kV towers. At present, the station is serviced by three power transformers and the load is shared as follows:

T1A 15MVA 132/33kV - Owena and Igbara-Oke feeders
T2A 30MVA 132/33kV - Akure T2B and T2C feeders
T3A 60MVA 132/33kV - Owo, Ado-Ekiti & Oba-Ile feeders

Akure 132kV Injection substation, the source of supply to Akure Township and environs is critically evaluated; the load growth trend of each 132/33kV power transformers is determined using statistical methods.

In this work, the least squares method is used in the load forecast based on statistical data obtained. Other known methods exist in literature for load forecast, but the least squares method (simple extrapolation technique) is quite simple and easy in practice since it gives a better estimation of regression line and hence, eliminates the human error inherent in other methods (Nwachukwu, 2006). The least squares method is in two stages:

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i. The statistical data observed for a long period of time is processed and summarized to obtain a particular trend.

ii. The trend obtained in the first stage is used for the actual forecast (extrapolation).

2. Methodology

Data Collection

Data source can be classified into two major areas: primary and secondary sources. Secondary sources refer to data from documents while primary sources may include direct observations, mail, questionnaire and personal interview. (Nwachukuwu, 2005). The initial data for the choice of load growth trend in Akure 132kV Transformer substation (T.S.) was obtained from the monthly maximum load (MW) of station reading sheets (2003-2013).

Moving Averages

A moving average is a simple arithmetic mean. The moving average Y_{t1} (P_{max} MW), Y_{t2}....., Y_{tn} is obtained by replacing each successive, overlapping sequence of k observations in the series by the mean of that sequence. The mean of the first k observations Y_{t1}, Y_{t2}....., Y_{tk} is computed and placed at the centre of the sequence. The mean of the second k observations Y_{t2}, Y_{t3}....., Y_{t+1} is also computed and placed appropriately; and so on. k is the order (term) of the moving average. (Nwachukwu, 2005).

The overall goal behind moving average is for smoothening actual growth dynamics.

Let

t = No of years from 2003 – 2013
Y_t= Maximum load (P_{max} MW)
k = 5

$\bar{Y}_t$ = Moving average

$$\bar{Y}_t = \frac{Y_{t1} + Y_{t2} + \dots + Y_{tk}}{K} \qquad 2.1$$

Linear Regression Model

The measurements that are available for the linear regression analysis come in pairs; (X_1, Y_1), $(X_2 Y_2)$, ..., (Xn, Yn) where the measurements $(X_i Y_i)$ are taken on the same entity called the unit of association.

The two variables X and Y are linearly related if their relationship can be expressed by the following linear model:

$$Y_i = \alpha + \beta x_i + e_i \qquad 2.2$$

Where α and β are parameters called the regression constant and regression coefficient, respectively; and e_i is a random variable with mean zero and variance δ^2.

The following assumptions underlie the linear regression model:

(a) The values of the independent variable x may be either fixed or random.

(b) For each value of x, there is a sub-population of y values. The sub-populations must be at least appropriately normally distributed for most the inferential processes of estimation and hypothesis testing to be valid.

(c) The magnitude of the measurement error in x is negligible

(d) The variance of the sub-populations of y are all equal

(e) The means of the sub-populations of y, all lie on the same straight line

(f) The y values are statistically independent((Nwachukwu, 2005)

Sample Regression Equation

Under the assumptions that underlie the linear regression model, we stated that the means of the sub-populations of Y all lie on the same straight line. This is an assumption of linearity and hence,

$$\mu_{x/y} = \alpha + \beta x_i \qquad 2.3$$

Where $\mu_{x/y}$ is the mean of the sub-populations of Y values; α and β represent respectively the y-intercept and slope of the line on which all the sub-population means are assumed to lie.

Equation 2.3 is an equation of a straight line and describes the true relationship between x and $\mu_{x/y}$. The parameters α and β are unknown. In regression analysis we make effort to estimate α and using sample results, in order to make inferences about the time regression line of Y and X. The estimated regression equation is given by

$$Y = a + bx \qquad 2.4$$

Where a and b are numerical constants that estimate α and βrespectively. a is an estimate of the intercept on Y-axis and b is an estimate of the regression coefficient.

The estimation of the regression equation can be made using the free-hand method ("eye-fitted" method) or the method of least squares.

In this work, the method of least squares is used to estimate and forecast the load growth on the power transformers at Akure Transformer Substation and the FUTA line.

The Least Squares Method

The least squares method is best suited for load growth estimate and forecast because it eliminates the human judgment inherent in the free-hand method of estimating the regression line, and gives one line only, which is the line of best fit. (Nwachukwu, 2006)

Using equation 2.2, the residuals, ei can be given as:

$$e_i = Y_i - (\alpha + \beta x_i)$$

Taking the sum of squares of the residuals we have

$$\sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} [Y_i - (\alpha + \beta x_1)]^2 \qquad 2.5$$

The least squares estimators of α and β are those values of α and β which minimize

$$\sum_{i=1}^{n} e_i^2$$

These values are the constants a and b in equation 2.4; and can be obtained by solving the following two normal simultaneous equations; which were derived using differential calculus.

$$\sum Y = na + b\sum X \qquad 2.6$$

$$\sum XY = a\sum X + b\sum X^2 \qquad 2.7$$

Solving simultaneously for a and b, we have

$$a = \frac{\sum Y \sum X^2 - \sum X \sum XY}{n\sum X^2 - (\sum X)^2} \qquad 2.8$$

and

$$b = \frac{n\sum XY - \sum X \sum Y}{n\sum X^2 - (\sum X)^2} \qquad 2.9$$

All summations are taken over the sample observations i = 1,2…,n. If we compute b first we can then obtain, a, using the expression

$$a = \bar{Y} - b\bar{x} \qquad 2.10$$

Linear Regression and Time Series

The time series data Y occur in sequence of time, t. The variable Y therefore depends on time, t. To estimate the equation of the trend line in time series analysis, the least squares method is used. Equation 2.4 (equation of the trend line) becomes:

$$Y = a + bt \qquad 2.11$$

where

$$b = \frac{n\sum XY - \sum X \sum Y}{n\sum X^2 - (\sum X)^2} \qquad 2.12$$

and

$$a - \bar{Y} - b\bar{x} \qquad 2.13$$

Table 2.1: Five-year moving average on T1A, T2A and T3A Transformers *Pmax*(2003 - 2013)

S/N	Year (t)	T1A		T2A		T3A		FUTA FEEDER	
		$Y_t(MW)$	$\overline{Y}_t(MW)$	$Y_t(MW)$	$\overline{Y}_t(MW)$	$Y_t(MW)$	$\overline{Y}_t(MW)$	$Y_t(MW)$	$\overline{Y}_t(MW)$
1	2003	6.5		21.0		15.0		0.25	
2	2004	6.8		21.5		20.2		0.28	
3	2005	7.8	7.68	25.0	23.20	24.5	22.74	0.31	**0.33**
4	2006	8.8	8.38	24.5	23.92	29.0	24.94	0.39	**0.37**
5	2007	8.5	9.32	24.0	24.52	25.0	26.40	0.43	**0.41**
6	2008	10.0	10.06	24.6	24.36	26.0	27.30	0.44	**0.45**
7	2009	11.5	10.66	24.5	24.26	27.5	27.40	0.48	**0.47**
8	2010	11.5	11.40	24.2	24.42	29.0	28.40	0.49	**0.50**
9	2011	11.8	11.80	24.0	24.50	29.5	29.50	0.50	**0.56**
10	2012	12.2		24.8		30.0		0.60	
11	**2013**	**12.0**		**25.0**		**31.5**		**0.72**	

Table 2.2: Computation of Load growth trend line for T1A by Method of Least Square (MLS)

S/N	Year (t)	Load (Y)	Code for t (U)	UY	U^2
1	2003	6.50	-5	-32.50	**25**
2	2004	6.80	-4	-27.20	**16**
3	2005	7.80	-3	-23.40	**9**
4	2006	8.80	-2	-17.60	**4**
5	2007	8.50	-1	-8.50	**1**
6	2008	10.00	0	0.00	**0**
7	2009	11.50	1	11.50	**1**
8	2010	11.50	2	23.00	**4**
9	2011	11.80	3	35.40	**9**
10	2012	12.20	4	48.80	**16**
11	2013	12.00	5	60.00	**25**
		∑Y = 107.40	**∑ U = 0**	**∑ UY = 69.5**	**$\sum U^2 = 110$**

However, equations 2.11 and 2.12 can be further simplified by coding t (U) such that

$$\sum u = 0$$

In this case we have

$$b = \frac{\sum UY}{\sum U^2} \qquad 2.14$$

$$a = \bar{Y} = \frac{\sum Y}{n} \qquad 2.15$$

3 Results and Discussion

3.1 Results

The results of the values for five-year moving averages on T1A, T2A, T3A and FUTA line based on the expression (2.1) are shown in Table 2.1.

The results of the trend line equations for T1A, T2A and T3A and FUTA 11kV line based on the expressions (2.11), (2.14) and (2.15) are also shown on tables 2.2, 2.3, 2.4 and 2.5 and the forecast for 10 years (2023) are: 19.24MW, 28.02MW, 45.02MW and 1.05MW respectively.

Table 2.3: Computation of Load growth trend line for T2A by Method of Least Square (MLS)

S/N	Year (t)	Load (Y)	Code for t (U)	UY	U^2
1	2003	21.0	-5	-105.0	**25**
2	2004	21.5	-4	-86.0	**16**
3	2005	25.0	-3	-75.0	**9**
4	2006	24.5	-2	-49.0	**4**
5	2007	24.0	-1	-24.0	**1**
6	2008	24.6	0	0	**0**
7	2009	24.5	1	24.5	**1**
8	2010	24.2	2	48.4	**4**
9	2011	24.0	3	72.0	**9**
10	2012	24.8	4	99.2	**16**
11	2013	25.0	5	125.0	**25**
		∑Y = 263.1	**∑ U = 0**	**∑ UY=30.1**	**$\sum U^2$= 110**

Table 2.4: Computation of Load growth trend line for T3A by Method of Least Square (MLS)

S/N	Year (t)	Load (Y)	Code for t (U)	UY	U^2
1	2003	15.0	-5	-75.0	**25**
2	2004	20.2	-4	-80.8	**16**
3	2005	24.5	-3	-73.5	**9**
4	2006	29.0	-2	-58.0	**4**
5	2007	25.0	-1	-25.0	**1**
6	2008	26.0	0	0	**0**
7	2009	27.0	1	27.5	**1**
8	2010	29.0	2	58.0	**4**
9	2011	29.5	3	88.5	**9**
10	2012	30.0	4	120.0	**16**
11	2013	31.5	5	157.0	**25**
		∑Y = 287.2	**∑ U = 0**	**∑ UY = 138.7**	**$\sum U^2$ = 110**

Using equations 2.11, 2.14 and 2.15, we have

$$Y = a + bt$$

$$a = \bar{Y} = \frac{\sum Y}{n} = \frac{107.4}{11} = 9.7636$$

$$b = \frac{\sum UY}{\sum U^2} = \frac{69.5}{110} = 0.6318$$

$$Y = 9.7636 + 0.6318t$$

For t= 15, y = 19.24 MW

Using equations 2.11, 2.14 and 2.15, we have

$$Y = a + bt$$

$$a = \bar{Y} = \frac{\sum Y}{n} = \frac{263.1}{11} = 23.92$$

$$b = \frac{\sum UY}{\sum U^2} = \frac{30.1}{110} = 0.2736$$

$$Y = 23.92 + 0.2736t$$

For t= 15, y = 28.02 MW

Table 2.5: Computation of Load growth trend line for FUTA 33kV feeder by Method of Least Square

S/N	Year (t)	Load (Y)	Code for t (U)	UY	U^2
1	2003	0.25	-5	-1.25	25
2	2004	0.29	-4	-1.12	16
3	2005	0.31	-3	-0.93	9
4	2006	0.39	-2	-0.78	4
5	2007	0.43	-1	-0.43	1
6	2008	0.44	0	0	0
7	2009	0.48	1	0.48	1
8	2010	0.49	2	0.98	4
9	2011	0.50	3	1.50	9
10	2012	0.60	4	2.41	16
11	2013	0.72	5	3.60	25
		$\sum Y = 4.89$	$\sum U = 0$	$\sum UY = 4.45$	$\sum U^2 = 110$

Table 2.6: Load Forecast on $T1A$, $T2A$, $T3A$ and FUTA FEEDER

Year (t)	Code for t (u)	$T1A$ $P_{max}(MW)$	$T2A$ $P_{max}(MW)$	$T3A$ $P_{max}(MW)$	FUTA FEEDER $P_{max}(MW)$
2014	6	13.55	25.56	33.67	0.6877
2015	7	14.19	25.83	34.94	0.7305
2016	8	14.82	26.12	36.20	0.7682
2017	9	15.45	26.38	37.46	0.8084
2018	10	16.08	26.65	38.72	0.8487
2019	11	16.71	26.93	39.98	0.8890
2020	12	17.35	27.20	41.24	0.9293
2021	13	17.98	27.48	42.50	0.9695
2022	14	18.61	27.75	43.76	1.0098
2023	**15**	**19.24**	**28.02**	**45.02**	**1.0500**

Using equations 2.11, 2.14 and 2.15, we have

$$Y = a + bt$$

$$a = \bar{Y} = \frac{\sum Y}{n} = \frac{4.89}{11} = 0.4445$$

$$b = \frac{\sum UY}{\sum U^2} = \frac{4.45}{110} = 0.0405$$

$$Y = 0.4445 + 0.0405t$$

For t = 15, y = 1.05 MW

3.2 Discussion

In Table 2.1, T1A Transformer recorded an increase in load from 2003-2006. Thereafter, at 2007, the load started falling gradually and from 2008, the load started rising. The rise and fall of the load on T1A 15MVA 132/33kV transformer is normal in electric power system. Electric load profile cannot be linear and a lot of factors contribute to this scenarios ranging from forced outage as a result of frequency control to faults due to adverse weather conditions, equipment failure and switching operations. These also explain why T2A, T3A and FUTA line were recording increase and decrease in loads.

According to table 2.6, T1A, T2A, T3A and FUTA line load forecast up to the year 2023 will be 19.24MW, 28.02MW, 45.02MW and 1.05MW respectively. These represent 142.52% of T1A MVA maximum demand, 103.78% of T2A MVA maximum demand and 83.37% of T3A MVA maximum demand. It therefore implies that T1A 15MVA 132/33kV transformer will be highly over-loaded, T2A

30MVA 132/33kV transformer will be over-loaded and T3A 60MVA 132/33kV transformer will not be over-loaded. In the other hand, the age and indeed the operating time of T1A will be quite enormous and can seriously affect the reliability of the transformer.

Note that reliability of a system is given by

$$R = e^{-\lambda t}$$

Where λ = failure rate (% hr) T

= operating time (hrs or year)

·Indeed, the useful period of T1A must have been elapsed going by the relatively long period of its operation (1968 - 2023). It is expected to be in the wear-out period of its lifecycle by now. These would be increasing in failure rate as a result of deteriorating and wear-out parts. This may cause corrosion, oxidation of transformer oil and finally break-down of insulation of the windings causing frequent open-circuiting or short-circuiting of the windings to the frame (Oroge, 1991).

T2A is bound to fail due to the above reasons but the failure rate will be gradual. The operating time of T2A will be 45 years (1978-2023). T3A is in good operating condition and the failure rate is very slim. It is highly reliable, can accommodate more loads well beyond the year 2023. Its operating time will be 21 years (2002-2023).

Hence, FUTA 33kV feeder that receives supply from the secondary of T3A 60MVA 13/33kV transformer is justified. (i).
T1A was manufactured in 1964 and commissioned in 1968. (ii).
T2A was manufactured in 1978 and commissioned in 1978. (iii).
T3A was manufactured in 2000 and commissioned in 2002.

4 Conclusions and recommendations.

4.1 Conclusions

On the analysis of the results of the computations of power growth trend on Akure 132kV Transformer substation power transformers T1A, T2A, T3A and FUTA 33kV line, the following conclusion can be made:

I. T1A 15MVA 132/33kV transformer will be over-loaded in 2023 having a load forecast estimate of 19.24MW representing 142.52% of its MVA maximum demand, hence T1A cannot be used to feed FUTA 33KV line. Also, the reliability index of T1A is very having a very long operation time.

ii. T2A 30MVA 132/33kV transformer will also be over-loaded in 2023 with a load forecast estimate of 28.02MW representing 103.78% of its MVA maximum demand. The reliability of this transformer is fair but if it is loaded above its maximum carrying capacity, it will fail sooner than later.

iii. T3A 60MVA 132/33kV transformer is best suited feeding FUTA 33kV line which would have load forecast estimate of 45.02 MW in 2023 representing about 83.37% of its MVA maximum demand and more importantly, the high reliability of the transformer confirmed the choice.

iv. FUTA 33kV line load forecast estimate is expected to hit 1.05MW in the year 2023.

4.2 Recommendations

I. FUTA 33kV line that presently receives potential from T3A 60MVA 132/33kV transformer secondary is highly justified.

ii. The management of transmission company of Nigeria should as a matter of urgency upgrade transformer T1A 15MVA and T2A 30MVA 132/33kV to at least 30MVA and 60MVA respectively in order to carter for the increasing loads in Akure and environs.

iii. In event that there is paucity of funds to embark on the upgrade recommended above, serious load shedding on T1A and T2A are required to be carried out by the operating personnel. This will reduce over-loading of the transformers thereby avoiding inter-turn winding (winding faults) of the transformer.

iv. Trend line equations for long term load forecast using EXCEL is recommended to ascertain the correctness of the methodology used in this work.

v. Planning engineers and electrical system operators can use the outcome of this study for proper planning and operations of the network.

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