American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-11, Issue-02, pp-12-18
www.ajer.org
Research Paper Open Access

Evaluation of the Inconsistencies in the Annual Load Curve of a Model Sub-Transmission Line

ADELOYE A.A[1], ADEOYE O.S[2], FOLAYAN G.B[3]
Department of Electrical and Electronic Engineering, School of Engineering, The Federal Polytechnic, Ado-Ekiti, Ekiti State, Nigeria.

Abstract- *This research establishes and evaluates the daily load curves of a model 132 kV sub-transmission line that connects a bulk power supply centre and a district distribution network in the Nigerian Western Grid - Akure. The research intention of this effort identifies the operational inconsistencies caused primarily by load fixing, load shedding and outage events. It also identifies the existing line performance indices along the network. Circuit diagrams of Osogbo and Akure 132 kV switching substation along with the half-hourly active and reactive power components in MW and MVar respectively, for a period of 12 months, were collected from the National Control Centre, Osogbo (NCC). Descriptive load statistics (maximum, mean, and standard deviations) of the half-hourly power data for the study period were evaluated in order to obtain half-hourly and daily maximum and minimum values in MW and MVar, which are relevant to power flow calculations in the sub-transmission line. The half-hourly phase angles and power factors for the study period were also determined concurrently. The daily load curve for each month and the study year were developed by plotting the half-hourly maximum statistics of data using Microsoft Excel spreadsheet. Results obtained are pertinent for the development and daily operation planning of Akure district distribution network.*

Keywords: *Load curve, sub-transmission, line performance, operation planning, distribution network and load statistics.*

Date of Submission: 05-02-2022 Date of acceptance: 18-02-2022

I. INTRODUCTION

The Electricity Corporation of Nigeria (ECN), a precursor of National Electric Power Authority (NEPA) -renamed Power Holding Company of Nigeria (PHCN) - was established as a statutory public corporation in 1951. The company took over power generation projects of the government which were carried out through the Public Works Department and from four native authorities. Between 1952/1953, the country generated 165 MW of power. Most of it was provided by ECN. During the following decade, the firm went through an expansion period increasing transmission lines available in Southern Nigeria; this was largely due to the rise in urbanization and demand for electricity. By 1964, the company had added additional power plants including one at Kano producing 6 megawatts of electricity and another at Ijora, Lagos producing 86.25 MW. It also opened new plants along the Oji river (25.5MW) and Afam (20MW) [2]. An Eastern grid along Afam-Port Harcourt-Aba and Onitsha Enugu-Nsukka with additional extensions at Nsukka, Calabar and Umuahia was also integrated to the National grid. [1][2]

SIGNIFICANCE OF OSOGBO-AKURE 132 kV TRANSMISSION LINE

1964 was the year that a western grid was created along Lagos-Ibadan-Ilorin with extensions at Abeokuta, Osogbo, Akure, Benin and Sapele. The Osogbo - Akure 132 kV annex of the western network spans 93 kilometres in route length. It passes through Kajola, Idominasi and Ilesha towns in Osun State before terminating at Akure Transmission Substation. The conductor type is Aluminium Conductor Steel Reinforced (ACSR) and the entire length is paired. It is a single circuit radial line that is supported by 366 steel towers. This network provides bulk electric power to domestic commercial and industrial load points in Akure metropolis.[3][4] The rate of production in the industries, general working condition and the living circumstances of the inhabitants of this reference region is enhanced through the installation of this extension of the national transmission network. Regrettably, this transmission line is still the sole source of bulk power supply to Akure metropolis that hosts 5,665,524 persons. [2][3]

II. METHODOLOGY

The circuit diagrams of the Osogbo and Akure 132 kV switching substations and the half hourly active and reactive power components for a period of twelve months were obtained from the National Control Centre, Osogbo. The substation circuit diagrams obtained are presented in figures 1 and 2 while the power components supplied for every half hour of each day in the month was tabulated as shown in Table 1.

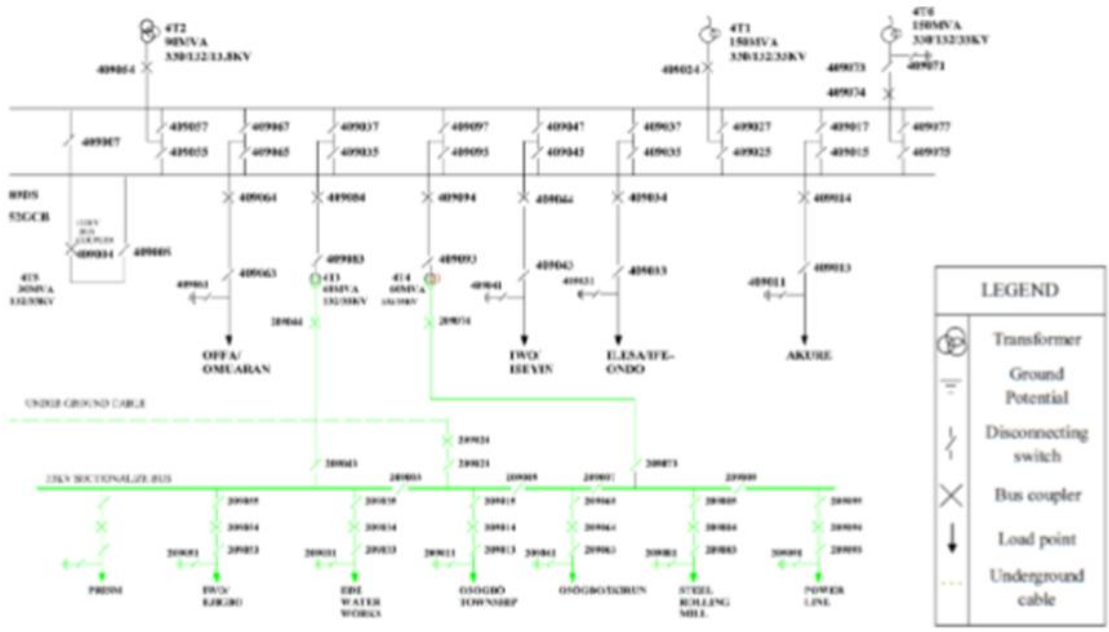

FIGURE: 1 OSOGBO 132/33 kV T.S SINGLE LINE CIRCUIT DIAGRAM
Source: Archives of National Control Centre, Osogbo, Osun State, Nigeria

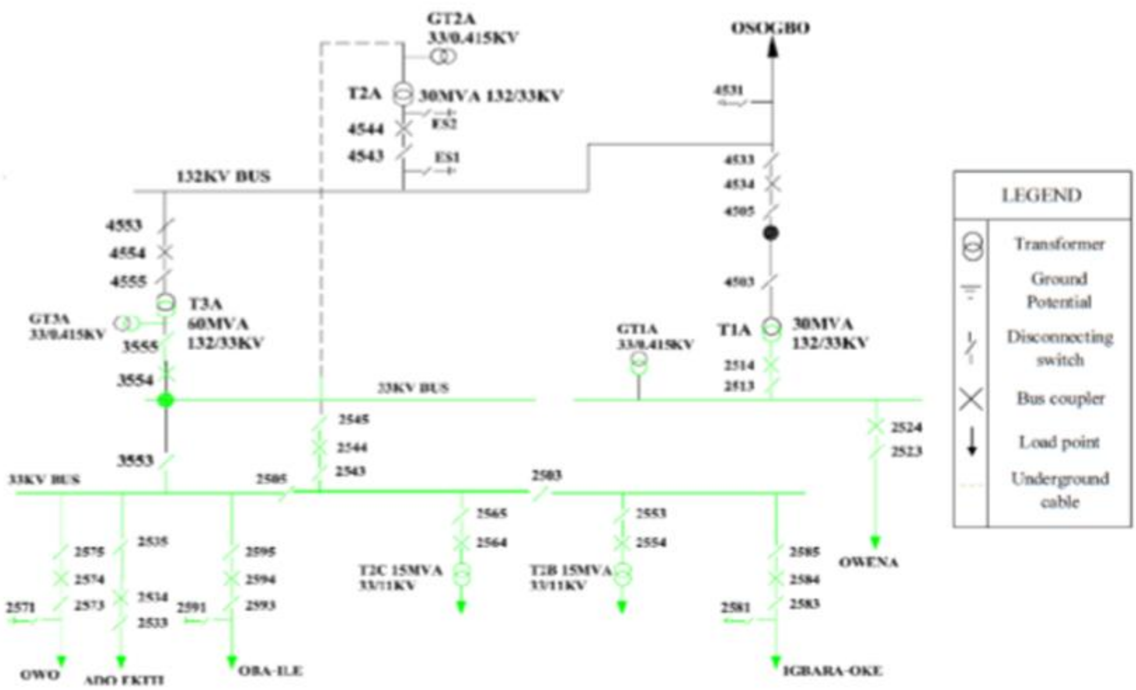

FIGURE: 2 AKURE 132/33 kV T.S SINGLE LINE CIRCUIT DIAGRAM
Source: Archives of National Control Centre, Osogbo, Osun State, Nigeria

TABLE .1Sample of the half-hourly daily load record

Time	Voltage	Active Power	Reactive Power
Minutes	*(kV)*	*(MW)*	*(MVar)*
00:00	135	34	15
00:30	135	30	14
01:00	138	31	12
01:30	136	31	13
02:00	136	32	14
02:30	137	31	14
03:00	137	32	13
03:30	137	33	14
04:00	136	32	13
04:30	131	31	14
05:00	135	13	15
05:30	136	35	16
06:00	135	38	17
06:30	136	37	16
07:00	137	35	15
07:30	137	36	15
08:00	136	30	13
08:30	135	32	16
09:00	136	37	20
09:30	136	37	20
10:00	136	18	8
10:30	137	18	8
11:00	135	18	9
11:30	135	18	9
12:00	135	18	9
12:30	135	18	8
13:00	134	16	9
13:30	135	16	6
14:00	135	16	6
14:30	135	16	7
15:00	134	32	16
15:30	134	32	16
16:00	131	42	25
16:30	132	39	21
17:00	133	26	10
17:30	133	26	10
18:00	133	26	10
18:30	135	30	11
19:00	137	32	11
19:30	136	29	9
20:00	136	23	8
20:30	134	24	8
21:00	136	26	8
21:30	134	28	9
22:00			
22:30	135	28	9
23:00	136	30	9
23:30	138	31	10
24:00	139	32	11

Source: Archive of Power Holding Company of Nigeria (PHCN) 132 kV Switching Substation, Osogbo, Osun State, Nigeria.

Consequently, a daily load curve was plotted from the tabulated data in order to examine the consistency in power transmission every 24 hours. A sample can be observed in figure 3 where the gaps represent incidences electric power failure.

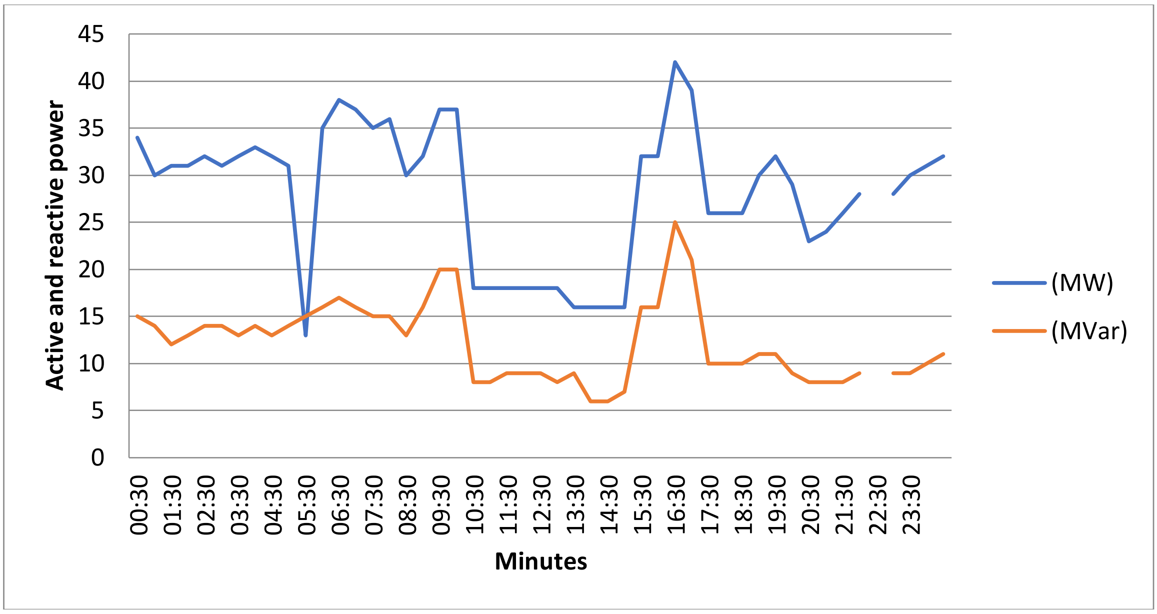

FIGURE 3 Specimen Graph of daily half hourly Readings of Load at 132 kV.

Microsoft Office Excel 2007® was used for the computation of the phase angle of the apparent power $MVA\ (\theta)$ and power factor for each day in the 12 months duration. These values were computed from the relationship represented in Eq. 1 and
2 respectively [6][7][10].

$$Phase\ angle\ (\theta) = tan^{-1}\frac{Q(MVar)}{P(MW)} = tan^{-1}S(MVA) \qquad (1)$$

$$Power\ factor\ (pf) = cos(phase\ angle) = cos(\theta) \qquad (2)$$

Afterwards, the mean and standard deviation (standard error) of active and reactive power components for every 30 minutes in each day of the 12 months were also calculated from using Eq. 3 to 8 and tabulated in table 2 [8][9][11].

$$Half-hourly\ mean\ of\ active\ power\ = \frac{\sum_{i=1}^{365} P_i(MW)}{365} \qquad (3)$$

$$Half-hourly\ mean\ of\ reactive\ power\ = \frac{\sum_{i=1}^{365} Q_i(MVar)}{365} \qquad (4)$$

$where\ i\ represents\ the\ half\ hourly$
$detail\ of each\ day\ in\ the\ month$

$$\sigma_P = \sqrt{\{\frac{\sum_{i=1}^{365} f(P_i\,(MW) - \bar{x}_P)^2}{N}\}} \qquad (5)$$

$$\sigma_Q = \sqrt{\{\frac{\sum_{i=1}^{365} f(Q_i(MVar) - \bar{x}_Q)^2}{N}\}} \qquad (6)$$

$where\ \sigma_P\ and\ \sigma_Q\ are\ standard\ deviations\ of active\ and\ reactive\ power$
$from\ their\ mean\ values\ \bar{x}_p,\ \bar{x}_Q$

$$Mean\ active\ power\ (\bar{x}_P) = \frac{\sum_{i=1}^{365} f_i\,P_i}{N} \qquad (7)$$

$$Mean\ reactive\ power\ (\bar{x}_Q) = \frac{\sum_{i=1}^{365} f_i\,Q_i}{N} \qquad (8)$$

$f = frequency\ of\ each\ value\ observed$
$N = Number\ of\ observations\ of P_i(MW)\ and\ Q_i(MVar)$
$i = half\ hourly\ detail\ of each\ day\ in\ the\ month$

Next, the coefficient of variation of the standard deviation for the 12 months was computed from the expression in Eq. 9 and 10. The values obtained were also recorded in table 2 [12][13][14][16].

$$Coefficient\ of\ variation_{MW} = \frac{\sigma_{P(i,j)}}{\bar{x}_{P(i,j)}} \times 100\% \qquad (9)$$

$$Coefficient\ of\ variation_{MVar} = \frac{\sigma_{Q(i,j)}}{\bar{x}_{Q(i,j)}} \times 100\% \qquad (10)$$

$where\ i = \{1,2,3, \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots .. ,365\}$

$j = \{0{:}30, 1{:}00, 1{:}30, \dots \dots \dots \dots \dots .. ,24{:}00\}$

$half\ hourly\ iteration.$

III. RESULTS AND DISCUSSION

The phase angle of the apparent power $MVA\,(\theta)$ and power factor obtained were computed accordingly after which the graphs of maximum active power and standard deviation of the maximum active power from the mean for the entire year were produced and presented in table 2.

TABLE 2 SUMMARY OF 2009 MONTHLY STATISTICS: Maximum and mean half hourly estimates of active and reactive power beginning from 12 midnight for 24 hours

Minutes	MAX, MW	MAX, MVar	MEAN, (MW)	MEAN, (MVa)	STDVA, (MW)	Coeff of Var	STDVA, (MVa)	Coeff of Var	Phase angle of MVA (θ)	Power factor
0	68	32	58.73	30.67	4.80	8.17	1.44	4.68	25.20	0.90
00:30	58	48	56.42	35.00	1.62	2.87	8.00	22.86	39.61	0.77
01:00	70	32	56.33	29.83	5.10	9.06	2.08	6.98	24.57	0.91
01:30	57	32	55.27	29.42	1.68	3.04	2.61	8.87	29.31	0.87
02:00	58	31	55.50	29.42	2.54	4.58	1.98	6.71	28.12	0.88
02:30	58	31	55.50	29.67	2.61	4.70	1.30	4.39	28.12	0.88
03:00	57	31	54.08	29.00	2.19	4.06	2.17	7.50	28.54	0.88
03:30	57	31	54.75	29.08	1.76	3.22	1.98	6.79	28.54	0.88
04:00	57	35	53.75	29.00	2.53	4.70	2.59	8.94	31.55	0.85
04:30	57	35	53.92	29.00	2.61	4.84	2.56	8.82	31.55	0.85
05:00	57	36	55.25	29.75	2.18	3.94	2.60	8.73	32.28	0.85
05:30	58	37	55.75	32.67	1.60	2.87	3.06	9.35	32.54	0.84
06:00	61	47	58.08	35.08	2.27	3.92	5.07	14.46	37.61	0.79
06:30	65	35	59.67	32.58	3.14	5.27	1.73	5.31	28.30	0.88
07:00	63	36	59.92	33.58	2.91	4.85	2.27	6.77	29.74	0.87
07:30	68	36	60.08	33.58	4.38	7.29	2.15	6.41	27.90	0.88
08:00	66	42	59.75	34.50	3.57	5.98	3.99	11.56	32.47	0.84
08:30	70	38	62.25	34.50	5.85	9.40	2.94	8.52	28.50	0.88
09:00	79	38	61.33	34.58	7.75	12.64	2.91	8.40	25.69	0.90
09:30	60	36	56.67	33.25	3.17	5.60	2.22	6.68	30.96	0.86
10:00	60	37	56.00	33.92	3.16	5.65	2.39	7.05	31.66	0.85
10:30	60	38	55.75	34.00	3.25	5.83	2.98	8.78	32.35	0.84
11:00	55	37	53.42	33.42	1.62	3.04	2.71	8.12	33.93	0.83
11:30	56	34	54.33	32.50	1.61	2.97	1.31	4.04	31.26	0.85
12:00	56	36	54.00	32.50	2.19	4.06	1.88	5.79	32.74	0.84
12:30	54	34	52.00	30.92	1.81	3.48	1.16	3.77	32.20	0.85
13:00	56	34	54.08	32.75	1.78	3.29	1.42	4.34	31.26	0.85
13:30	57	39	53.83	34.17	2.72	5.06	3.79	11.08	34.38	0.83
14:00	56	34	53.67	31.75	2.84	5.29	1.91	6.02	31.26	0.85
14:30	56	35	53.75	32.17	2.77	5.15	2.29	7.12	32.01	0.85
15:00	56	34	54.33	31.83	2.19	4.03	1.70	5.33	31.26	0.85
15:30	56	34	54.00	32.08	2.09	3.87	2.07	6.44	31.26	0.85
16:00	58	35	54.42	32.25	2.27	4.18	2.14	6.63	31.11	0.86
16:30	62	35	55.42	31.83	4.01	7.24	3.38	10.62	29.45	0.87
17:00	59	38	54.00	32.42	3.77	6.97	3.58	11.04	32.78	0.84
17:30	68	38	57.58	32.17	7.73	13.42	3.97	12.35	29.20	0.87

18:00	68	38	57.83	32.58	6.32	10.93	3.20	9.83	29.20	0.87
18:30	64	41	59.42	35.08	3.12	5.25	3.09	8.80	32.64	0.84
19:00	66	41	61.83	37.08	2.29	3.70	2.23	6.03	31.85	0.85
19:30	66	40	61.75	37.92	2.99	4.84	1.73	4.56	31.22	0.86
20:00	84	58	68.64	42.75	10.02	14.60	9.27	21.70	34.62	0.82
20:30	66	50	61.82	39.00	2.56	4.14	6.70	17.18	37.15	0.80
21:00	65	38	60.25	35.83	1.82	3.01	2.12	5.93	30.31	0.86
21:30	62	37	60.50	34.67	1.45	2.39	1.61	4.66	30.83	0.86
22:00	62	38	60.58	35.67	1.62	2.68	2.19	6.13	31.50	0.85
22:30	63	38	61.50	35.50	1.98	3.21	2.11	5.95	31.10	0.86
23:00	61	50	58.83	38.50	1.59	2.70	7.38	19.17	39.34	0.77
23:30	60	33	57.83	32.17	1.80	3.11	1.34	4.16	28.81	0.88
24:00:00	60	32	57.50	30.83	2.02	3.52	1.40	4.55	28.07	0.88
	84.00	**58.00**					**1.16**			
	54.00	**31.00**								

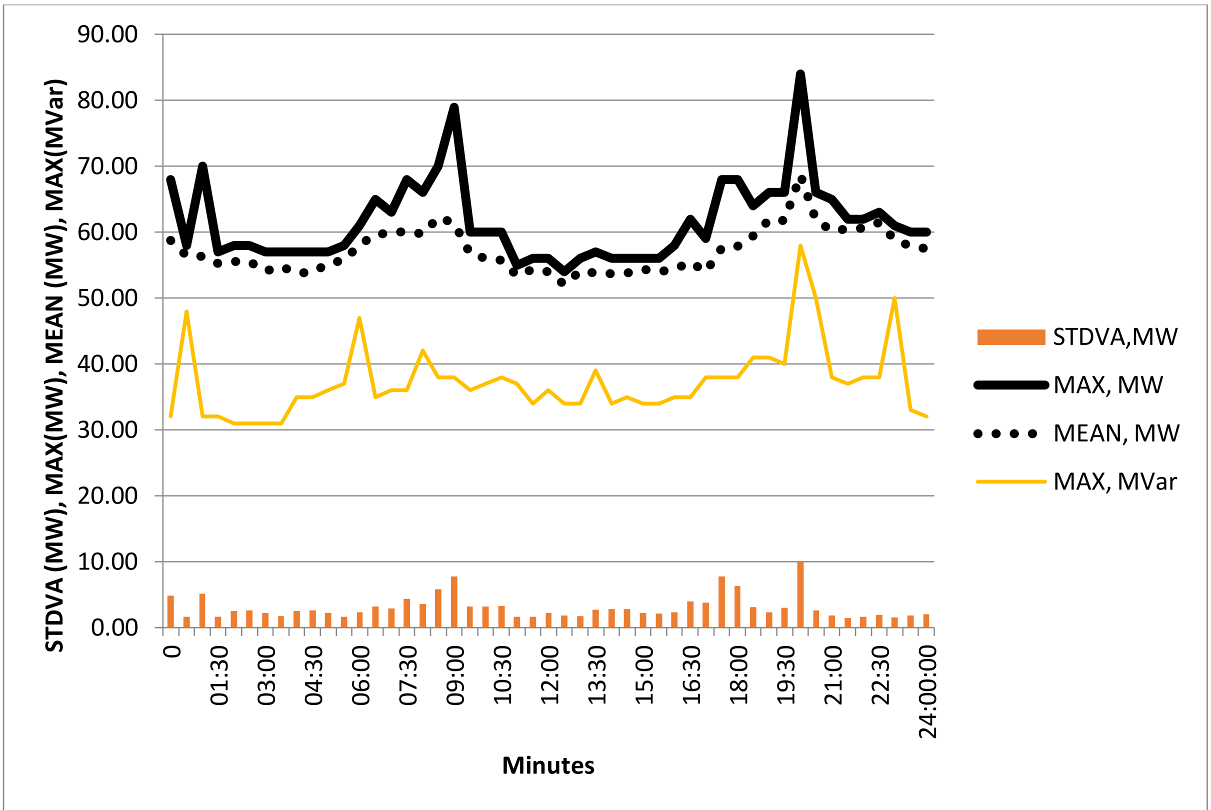

FIGURE 4 Graphs of maximum active and reactive power for each half-hour in the month, mean active power and standard deviation (standard error) of active power for every half-hour against time for the 2009

Maximum and mean half hourly estimates of active and reactive power: The half-hourly active and reactive power readings obtained from the sending end of the Osogbo-Akure 132 kV radial line were filtered through a Half-hourly Time Series Statistical Analysis Procedure. The first reason was to identify any outrageous value recorded in the process of typing in the values at the Osogbo end of the transmission line. The second intent was to accurately identify the maximum active and reactive power components transmitted through the line at every half hour of each month. This is because the most common way utilities quantify a circuit's load is the peak demand over a specific period of time. The third and final reason was to establish the maximum and minimum MAX, MW and MAX, MVar for the whole year.

These values are presented in the second and third columns of Table 2 under the captions MAX MW and MAX MVar respectively. Subsequently, the mean active and reactive power components (MEAN MW and MEAN MVar) were determined and compiled in the same table. Afterwards, the extent of deviation of the maximum active and reactive power components from their estimated mean values for 30 minutes duration was determined by computing their standard deviations. The results obtained for each of the 12 months were recorded as STDVA, MW and STDVA, MVar. Similarly the coefficient of variation of the active and reactive component of standard deviation was estimated for the 12 months duration. The values obtained were tabulated in Table 2. This index depicts the consistency of active and reactive power components. The Half-hourly Time Series Statistical Procedure was repeated for every 30 minutes detail of each month in order to arrive at a compilation for the year. This is presented in Table 2. The maximum MAX, MW and MAX, MVar for the whole year was identified as 84 MW and 58 MVar. 54 MW and 31 MVar were identified as minimum power constituents. Fig 4 is a compilation of the graphs of the STDVA MW, MAX MW, MEAN MW, and MAX MVar for twelve months. It particularly presents the disparity between the maximum and mean active power. The power components reached their peak values between 7:30-9:30am and 7:45-9:40pm monthly. These periods represent the monthly peak periods. The purpose of the chart is to observe the consistency and variation in the power transmission profile for each of the 12 months. The phase angle of the apparent power supplied at every half hour was computed and their corresponding power factor values were calculated. The values obtained for the entire year are compiled in Table 2. Power factor values that are less than 0.8 indicate a widely varying electric power supply. Significant voltage fluctuations do not support the smooth operation of some electrical equipment. Examples of such appliances are the electrocardiograph (a life support equipment) and some testing appliances being used in the various technical laboratories in the Akure. However, power factor values greater than 0.8 indicates that the load runs almost constantly. This is preferable from the utility point of view. It helps most electrical appliances in the south western metropolis to work long with high technical and economic indices.

IV. CONCLUSION

The study reveals the real and reactive power components of the Osogbo-Akure 132 kV transmission line at steady-state operating modes. At maximum operating mode, the values of real and reactive power components $P_2 \; and \; Q_2$ are 69.86 MW and 38.58 MVar respectively. These values represent the initial active and reactive components of the sending end apparent power at maximum and minimum mode operations. The peak and the least values of active and reactive power are also utilized for the assessment of the operation on the line. This is with a view to determining whether the line can support electric power transmission at maximum and minimum operating conditions.

REFERENCES

[1]. Adeloye A. A (2018) Assessment of the Operations of Osogbo – Akure 132 kV Transmission Line, Nigeria, Lambert Academic Publishing, Mauritius, pp 68-80

[2]. Adeloye A. A & Melodi A.O (2019). Design of an Alternative Lateral Line for Feeding a District Distribution Network from a Nigerian South Western Grid, Scientific Research Journal (SCRIJ), Volume VII, July 2019, pp 96-97.

[3]. Akure, Nigeria Metro Area Population 1950-2020, World Population Review, World Urbanization Prospects- United Nations population estimates and projections of major urban agglomerations

[4]. Alex, A. K. (2008, March 26). Category: Companies of Nigeria- National Electric Power Authority. Retrieved 18:24:53 August 22, 2010, from Nigerian Wiki Web site: http://ww.nigerianwiki.com. org

[5]. Cassaza, J., & Delea, F. (2003). Understanding Electric Power Systems (by the Institute of Electrical and Electronic Engineers). New Jersey: John Wiley and Sons, Inc.

[6]. Dugan, R. C., McGranaghan, M. F., Surya, S., & Beaty, W. H. (2004). Electrical Power Systems Quality, 2nd Edition. www.digitallibrary.com: McGraw Hill.

[7]. El-Hawary, M. E. (2000). Electrical Energy Systems. (pp. 125-126). Boca Raton, Florida: CRC Press, LLC.

[8]. Grigsby, L. L. (2006). Electric Power Engineering Handbook (Power Systems), 2nd Edition. New York: Taylor and Francis Group.

[9]. Grigsby, L. L. (2007). Electric Power Generation, Transmission and Distribution, 2nd Edition. In Price W. W, Electric Power Engineering Handbook (pp. 10, chapter 13), CRC Press.

[10]. Grigsby, L. L. (2007). Power System Stability and Control, 2nd Edition. In Karady G. G, Electric Power Engineering Handbook (pp. 1, chapter 8), CRC Press.

[11]. Meier, A. V. (2006). Electric Power Systems. (pp. 156-158, 166, 187, 229-233). Hoboken, New Jersey: John Wiley & Sons, Inc; A Wiley-Interscience publication.

[12]. Pabla, A. (2005). Electric Power Distribution, Fifth Edition.(pp. 310-314). Delhi: Tata McGraw-Hill.

[13]. Reeves, E.A, Heathcote, Martin. J. (2003). Newnes Electrical Pocket Book. 23rd Edition. (pp.205). Chennai, India: Laserwords Private Limited.

[14]. Saccomanno, F. (2003). Electric Power Systems - Analysis and Control. (pp. 1-4). Hoboken, New Jersey: IEEE Press.

[15]. Siemens, A. (1998). Electrical Engineering Handbook, Third Edition. (pp. 314-316). New Delhi, India: Mohinder Singh Sejwal for Wiley Eastern Limited.

[16]. Shirley, B, Shirley, N. (2010, July 11). Gauss-Seidel Power Flow Method. Retrieved 20:36:11, September 28, 2010, from Discussion: Wikipedia, the free encyclopaedia: http//en.wikipedia.org

[17]. Short, T. (2004). Electrical Power Distribution Handbook. (pp. 44-45). Boca Raton, Florida: CRC Press LLC.

[18]. Weber, C. (2005). Uncertainty in the Electric Power Industry. New York: Springer Science + Business Media Inc