**International Journal of Technical Research and Applications e**-ISSN: 2320-8163,
www.ijtra.com Volume 4, Issue 4 (July-Aug, 2016), PP. 36-40

# INVESTIGATION OF ENERGY LOSS IN A TRANSMISSION SUBSTATION USING ONITSHA 330/132KV AS A CASE STUDY

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*Abstract*— **In transmitting power, energy losses both technical and non-technical occur within the substations and should always be monitored. In this paper, energy loss assessment is carried out in detail using Statistical data collected for two months from all substations under Onitsha 330/132KV transmission substation. In all six substations, statistical data were collected; analysed then energy loss and average energy loss for the month of January and February, 2016 were calculated to be -0.03% and 0.14% respectively which was used to determine how efficient and effective Onitsha 330/132kV transmission substation was transmitting and distributing power during the period. Graphs were plotted using MATCAD to show the percentage of energy loss and effect of station service on energy loss for two months. Probable observed problems where pointed out and suggestions were given to reduce losses and to improve system efficiency.**

***Index Terms*__Energy loss, Transmission substation, Transmission loss, MATCAD, Station service**

## I. INTRODUCTION

Electrical energy is the most important form of energy to modern day lifestyle [1]. Electrical energy can be generated through conventional and non-conventional means at the best and various locations connected through transmission lines. It is transmitted from long distance to load centres at high voltage using transmission lines and stepped down to a medium and low voltage level for distribution and consumers respectively. Total system energy loss indicates how effectively and efficiently a power system is transmitting power to its consumers [2]. Hence it has become one of the indices for key performance in the power industry. Technical losses represent an economic loss for the country and its optimization should be performed from country's perspective, regardless of institutional organisation of the sector and ownership of operating electricity utilities [3]. Most losses are caused by the technical loss as the non-technical loss is negligible in a transmission substation [2]. A transmission substation steps down extra high and high voltage to medium voltage at a very reliable, safe and efficient means. It consists majorly of transformers and switchgears. Transmission losses are losses that occur in transformers, switchgear contacts, transmission lines and reactors. Transmission loss is therefore the difference between the energy received from generating station and delivered to distribution stations [4]. It is the amount of energy units not accounted for in terms of monetary value. Energy meters are installed on feeders and transformers to monitor the energy consumed by consumers. These energy meters are not the usual prepaid energy meters we use at homes they are called maximum demand energy meters (MD). The energy meter gives real time of energy consumption on feeders and transformers. Therefore, the energy at different feeders and transformers are known and compared within the substation and the energy loss is determined.

### *A.* FORMS OF TRANSMISSION LOSSES

Energy losses in a power system are attributed to various causes at the generating stations, transmission substation and the distribution substation. Transmission loss = {Energy received (MWH) - Energy distributed at the feeders in (MWH)} (1.1)
Energy received (MWH) [4]

The various forms of losses are as follows;

- Losses from generating stations
1. Inappropriate location of billing meters
2. Generating station auxiliary services supplied from transmission stations

- Losses from transmission station
1. Transmission line losses due to energy dissipated as heat on conductors.
2. Transformer losses which comprises of core loss (Eddy current loss and Hysteresis loss, copper loss ($I^2R$) in the winding of the transformer).
3. Losses from reactor and other voltage control equipment in form of heat resulting from $I^2R$ loss and noise.
4. Losses due to loosed termination and high contact resistance at the joints along transmission lines, switchgears, and terminal equipment in transmission substations.
5. A low power factor in the system would result in large current which will cause $I^2R$ losses to increase.

- Losses from distribution station (Metering)
1. Feeders without billing meters

2. Malfunctioning of billing meters
3. Feeders with tampered meter
4. Error in reporting energy meter reading
5. Metering error due to mismatch between specification of instrument transformers and meters.

## II. HOTSPOT

Hotspot is the term used to describe a loosed contact heating up leading to high resistance on that joint which would be in a form of glow. The event that lead to energy production and these localized areas are popularly known as hot spot or partial discharges in equipment insulation [5]. The high resistance on that joint is as a result of high current on that spot which actually cause energy loss in form of heat.

This occurs often on conductor clamps, isolator contacts etc. and can be avoided by making sure all loosed contacts are properly tighten, frequent maintenance should be carried out on switchgears, avoid kinks on conductors and use of proper and standard size of conductor.

## III. TRANSFORMER LOSSES

Transformers are inductive in nature and they consume the power with lagging power factor. As the power factor falls below unity the current in the system increases increasing power loss ($I^2R$) [6]. But the key input for estimating transformer energy loss is the transformer load that determines the power factor and energy consumed [2]. Attempts can be made to minimize these losses.

Transformer losses are core losses (hysteresis loss and Eddy current loss) and copper loss ($I^2R$).

### A. CORE LOSSES

Taking place in iron/core part comprising of hysteresis losses and eddy current losses in the core considered to be constant irrespective of load.

Hysteresis losses: hysteresis loss is caused by the cyclic reversal of flux in the magnetic circuit and can be reduced by metallurgical control of the steel [7].

Eddy current loss: Eddy loss is caused by eddy currents circulating within the steel induced by the flow of magnetic flux normal to the width of the core, and it can be controlled by reducing the thickness of the steel lamination or by applying a thin insulating coating [7].

Eddy loss can be expressed as follows:

$$W = Kw^2B^2 \text{ watts} \qquad (1.2)$$

Where;

K = constant

w = width of the core lamination material normal to the flux

B = flux density

## IV. COPPER LOSSES OR LOAD LOSS

This takes place in the winding part. As a function of load current, can be divided into ($I^2R$) loss and stray losses. The stray losses are caused by eddy currents that produce stray electromagnetic flux in the windings, core, core clamps, magnetic shield and other parts of the transformer [2].

Stray loss: Leakage inductance is by itself largely lossless, since energy supplied to its magnetic fields is returned to the supply with the next half-cycle. However, any leakage flux that intercepts nearby conductive materials such as the transformer's support structure will give rise to eddy currents and be converted to heat. Mechanical vibration and audible noise transmission In addition to magnetostriction the alternating magnetic field causes fluctuating forces between the primary and secondary windings. This energy incites vibration transmission in interconnected metalwork, thus amplifying audible transformer hum [2].

## V. TRANSMISSION SUBSTATION

A transmission substation is the arrangement of transformers and switchgears in other to step down extra high voltage to high voltage and medium voltage or high voltage to medium voltage at a very reliable, efficient and safe means. The principal items are transformers, overhead lines, towers, circuit breakers, disconnect switches(isolators), bus-bars, shunt reactors, shunt capacitors, current and potential transformers, isolators, control and protection equipment[4]. Figure 1 shows a typical single line diagram (SLD) of a 132/33kV transmission substation

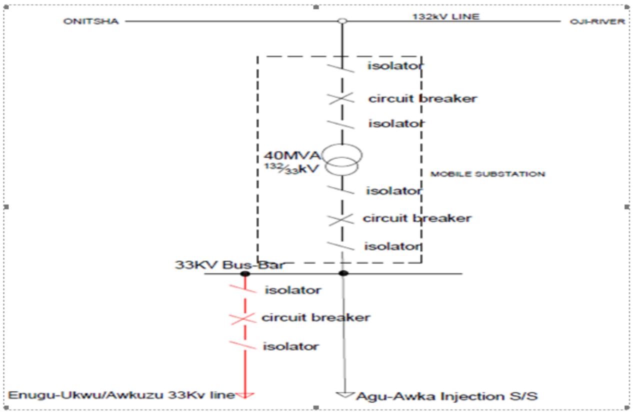


Figure 1; Typical single line diagram (SLD) of a 132/33kV transmission substation.

### *A. ONITSHA 330/132KV TRANSMISSION SUBSTATION*

Onitsha 330/132KV transmission substation has a total capacity of 480MVA, 330/132kV power transformer and 220MVA, 132/33kV power transformer. It evacuates the power generated from okpai generating station which has a capacity of 480MW through a 330kV double circuit transmission line. The substation is connected to the grid network through Alaoji 330kV T/L, Asaba 330kV T/L,

Benin (1) 330kV T/L, Benin (2) 330kV T/L and New Haven 330kV T/L. Also it transmits at 132kV to six (6) substations at different locations as shown in Table 1.0;
Table 1.0 shows 132kV substations that receives power from Onitsha 330/132kV Transmission Substation.

| S/N | SUB-STATION | TOTAL POWER TRANSFORMER CAPACITY(MVA) |
|---|---|---|
| 1 | Awka 132kV Substation | 60MVA 132/33KV |
| 2 | Agu-Awka 132KV Substation | 40MVA 132/33KV |
| 3 | Oji-River 132kV Substation | 30MVA 132/33KV & 15MVA 132/66KV |
| 4 | G.C.M 132kV Substation | 60MVA 132/33KV |
| 5 | Nsukka 66kV Substation. | 15MVA 66/33KV |
| 6 | Onitsha 132kV Substation | 220MVA 132/33KV |

## VI. LOSS CALCULATION APPROACH

The energy loss in Onitsha 330/132kV T/S was investigated by collecting metered energy received from generating station, metered energy transmitted to other 132kV transmission substations, metered energy distributed through 33kV feeders and metered energy used as station services within all transmission substations consumed every day.

*Station services is the energy consumed within the substation for control room utility, office utility, switchyard lighting, charging DC batteries etc and it is unaccounted for because energy consumed is not paid for.*

The energy consumed by each feeder on individual transformers in all the 132kVtransmission substation as listed in Table 1.0, receiving power from Onitsha 330/132kV T/S and its energy consumption is compiled on a daily bases for the month of January to February, 2016.

The energy consumed on the transformer is read from the secondary energy meter also the energy consumed on its outgoing feeders is also read from its individual energy meter. Table 1.1 shows the daily summation of the energy in MWhr from each transmission substation and energy loss is calculated.

Total energy loss= (Energy received – Energy distributed) – station services (1.3)

$$\text{Energy loss (\%)} = \frac{\text{Total energy loss}}{\text{Energy received}} \times 100\% \quad (1.4)$$

Table 1.1; Daily summation of the energy in MWhr from each transmission substation and energy loss calculated.

**MWHr SUMMATION IDENTIFYING SOURCE OF ENERGY LOST 01/01/2016**

| STATION | TRANSFORMER | ENERGY Difference (MWHr) | CTR | 33KV FDR NAME | ENERGY Difference (MWHr) | CT | 33KV FDR SUM ENERGY |
|---|---|---|---|---|---|---|---|
| ONITSHA 330/132 KV WORK CENTER | TR11 60MVA | 0 | 1200/1 | | | | |
| | | | | 3-3 | 107.65 | 400/1 | |
| | TR12 | 108.8 | 1200/5 | PP1 | 108.8 | | 108.8 |
| | | | | UNIT | | | |
| | | | | EZEIWEKA | | | |
| | TR13 | 661.34 | 1200/1 | NICCUS | 210.57 | 200/5 | 662.72 |
| | | | | | | 400/1 | |
| | | | | NNEWI | 344.50 | 800/1 | |
| | MBTR 132/33KV | 280.20 | 600/1 | UMUNYA | 151.38 | 400/5 | 278.97 |
| | | | | OBOSI | 127.59 | 400/5 | |
| | MBTR 132/11KV | 195.6 | 1200/1 | NWAZIKI | 195.6 | | 195.6 |
| | | | | WOLIWO | | | |
| | MBTR 2. 132/33KV | 400.56 | 1200/1 | AWADA 2 | 81.71 | 400/5 | 400.35 |
| | | | | A/BARRACKS | 318.64 | 800/1 | |
| AWKA SUB-STATION | TR3 30MVA 132/33KV | 309.4 | 600/1 | TR2 | 121.27 | 600/1 | 309.4 |
| | | | | TR4 | 188.13 | 400/1 | |
| | TR1 30MVA 132/33KV | 193.44 | 400/1 | AGULU | 187.87 | 600/1 | 197.95 |
| | | | | NENI | 10.08 | 400/1 | |
| AGU-AWKA SUB- | T1 40MVA 132/33KV | 161.2 | 1200/1 | AGU-AWKA | 161.2 | | 161.2 |
| | | | | FEEDER | | | |
| OJI-RIVER SUB-STATION | T1B 15MVA 132/66KV | 0 | 300/1 | NSUKKA | 0 | 200/1 | 0 |
| | | | | KINGSWAY | | N/A | |
| | T1A 30MVA 132/33KV | 260.5 | 600/1 | OJI LOCAL | 49.53 | 300/1 | 260.5 |
| | | | | W/WORKS | 19.87 | 400/1 | |
| | | | | ACHI | 102.92 | 400/1 | |
| | | | | COCA COLA | 1.01000E+00 | | |
| | | | | UDI | 87.57 | 400/1 | |
| GCM SUB-STATION | TR1 60MVA 132/33KV | 348.6000 | 1200/1 | GCM TR4 & GOLDEN OIL | 36.4000 | | 348.6000 |
| | | | | | | | |
| | | | | ATANI | 312.20 | | |
| NSUKKA SUB-STATION | T1A 7.5MVA 66/33KV | 66.00 | 150/5 | IBAGWA | -165.41 | 150/1 | 66 |
| | | | | INJECTION S/S | 231.4125 | | |
| | | | | T3 | 0.00 | 500/5 | |
| | T1B 7.5MVA 66/33KV | 106.90 | 200/1 | T2 | 105.54 | 200/1 | 105.54 |
| ASABA SUB-STATION | TR1 60MVA 132/33KV | 614.00 | | FDR 1 | 614.00 | | 614.00 |
| | TR2 60MVA 132/33KV | 0.00 | | FDR 2 | 0.00 | | |
| TOTAL | | 3706.942 | | | 3710.030 | | 3710.030 |
| **Total Energy Consumed within the Stations** | | | | | **0.663** | | |
| **Actual Energy Lost** | | | | | **-3.088** | | |
| **Total Energy lost** | | | | | **-2.424** | | |
| **Percentage lost** | | | | | **-0.07%** | | |

Source: Onitsha 330/132kV Transmission Substation (PC&M dept.), Transmission Company of Nigeria (TCN).

Table 1.1 shows a typical daily summation template of all energy received, distributed and consumed by all transmission substations. For the purpose of this paper the daily energy consumed by each substation for the month of January to February, 2016 has been summed, extracted, calculated and compiled in Table 1.2 below;

Table 1.2; Shows the Total Energy received and distributed in the month of January and February, 2016 for all 6 transmission substation.

| S/N | TRANSMISSION SUBSTATION | ENERGY RECEIVED (MWhr) | | ENRGY DISTRIBUTED (MWhr) | |
|---|---|---|---|---|---|
| | | **January** | **February** | **January** | **February** |
| 1 | Awka 132kV Substation | 16,681.61 | 9463.85 | 16, 869.91 | 9462.76 |
| 2 | Agu-Awka 132KV Substation | 9880.60 | 3005.7 | 9880.6 | 3005.7 |
| 3 | Oji-River 132kV Substation | 6163.10 | 5265.20 | 6138.77 | 5245.49 |
| 4 | G.C.M 132kV Substation | 14,563.20 | 14143.60 | 14,563.20 | 14143.60 |
| 5 | Nsukka 66kV Substation. | 5457.60 | 4551.50 | 5418.59 | 4551.90 |
| 6 | Onitsha 132kV Substation | 54,077.03 | 48300.21 | 52,913.09 | 48108.59 |

Table 1.3; shows the total energy received, distributed and station services consumed every day from the six transmission substations for the month of January, 2016.

| DATE | ENERGY RECEIVED(MWhr) | TOTAL ENERGY DISTRIBUTED(MWhr) | TOTAL STATION SERVICES | TOTAL ENERGY LOSS | ENERGY LOSS (%) |
|---|---|---|---|---|---|
| 1/01/16 | 3706.942 | 3710.03 | 0.663 | -2.424 | -0.07 |
| 2/01/16 | 3507.631 | 3511.638 | 0.708 | -3.298 | -0.09 |
| 3/01/16 | 3262.399 | 3257.120 | 0.705 | 5.984 | 0.18 |
| 4/01/16 | 3509.806 | 3513.791 | 0.70 | -3.285 | -0.09 |
| 5/01/16 | 3723.206 | 3725.761 | 0.665 | -1.890 | -0.05 |
| 6/01/16 | 3807.768 | 3812.503 | 0.653 | -4.082 | -0.11 |
| 7/01/16 | 3606.251 | 3607.319 | 0.674 | -0.393 | -0.01 |
| 8/01/16 | 4131.933 | 4122.277 | 0.709 | 10.364 | 0.25 |
| 9/01/16 | 3978.216 | 3983.319 | 0.701 | -4.402 | -0.11 |
| 10/01/16 | 3830.331 | 3830.189 | 0.767 | 0.909 | 0.02 |
| 11/01/16 | 3997.386 | 3998.004 | 0.802 | 0.185 | 0.00 |
| 12/01/16 | 3870.298 | 3872.966 | 0.806 | -1.863 | -0.05 |
| 13/01/16 | 4143.974 | 4147.64 | 1.282 | -2.508 | -0.06 |
| 14/01/16 | 4475.342 | 4477.591 | 0.884 | -1.366 | -0.03 |
| 15/01/16 | 4042.954 | 4043.749 | 0.796 | 0.001 | 0.00 |
| 16/01/16 | 3822.130 | 3824.278 | 0.825 | -1.322 | -0.03 |
| 17/01/16 | 3762.974 | 3769.704 | 0.883 | -5.847 | -0.16 |
| 18/01/16 | 3798.566 | 3803.653 | 0.942 | -7.145 | -0.19 |
| 19/01/16 | 4158.639 | 4157.680 | 0.868 | 1.826 | 0.04 |
| 20/01/16 | 3166.137 | 3170.871 | 0.839 | -3.894 | -0.12 |
| 21/01/16 | 3629.005 | 3627.721 | 0.784 | 2.067 | 0.06 |
| 22/01/16 | 3714.984 | 3714.216 | 0.856 | 1.623 | 0.04 |
| 23/01/16 | 3165.486 | 3166.958 | 0.561 | -0.910 | -0.03 |
| 24/01/16 | 3650.949 | 3651.616 | 0.969 | 0.301 | 0.01 |
| 25/01/16 | 3582.280 | 3583.650 | 0.698 | -0.672 | -0.02 |
| 26/01/16 | 4059.870 | 4023.420 | 0.761 | 7.411 | 0.18 |
| 27/01/16 | 3516.150 | 3532.70 | 0.826 | -15.724 | -0.45 |
| 28/01/16 | 3443.830 | 3438.490 | 0.738 | 6.078 | 0.18 |
| 29/01/16 | 3783.790 | 3788.810 | 0.741 | -4.279 | -0.11 |
| 30/01/16 | 3881.120 | 3878.610 | 0.733 | 3.243 | 0.08 |
| 31/01/16 | 3772.290 | 3777.29 | 0.690 | -4.310 | -0.11 |

Table 1.4 shows the total energy received, distributed and station services consumed every day from the six transmission substations for the month of February, 2016.

| DATE | ENERGY RECEIVED(MWhr) | TOTAL ENERGY DISTRIBUTED(MWhr) | TOTAL STATION SERVICES | TOTAL ENERGY LOSS | ENERGY LOSS (%) |
|---|---|---|---|---|---|
| 1/02/16 | 3789.09 | 3790.49 | 0.670 | -0.730 | -0.02 |
| 2/02/16 | 3954.38 | 3954.03 | 0.635 | 0.985 | 0.02 |
| 3/02/16 | 3650.05 | 3638.39 | 0.611 | 12.278 | 0.34 |
| 4/02/16 | 3500.62 | 3491.204 | 0.681 | 10.10 | 0.29 |
| 5/02/16 | 3980.52 | 3975.24 | 0.776 | 6.056 | 0.15 |
| 6/02/16 | 3968.02 | 3968.76 | 0.754 | 0.014 | 0.00 |
| 7/02/16 | 3935.95 | 3926.69 | 0.700 | 9.960 | 0.25 |
| 8/02/16 | 3799.46 | 3799.40 | 0.764 | 0.824 | 0.02 |
| 9/02/16 | 3937.15 | 3926.67 | 0.709 | 11.189 | 0.28 |
| 10/02/16 | 3870.32 | 3865.93 | 0.722 | 5.112 | 0.13 |
| 11/02/16 | 3209.57 | 3204.27 | 0.753 | 6.053 | 0.19 |
| 12/02/16 | 3443.830 | 3438.490 | 0.738 | 6.078 | 0.18 |
| 13/02/16 | 2367.40 | 2352.87 | 0.683 | 15.213 | 0.64 |
| 14/02/16 | 2958.64 | 2972.203 | 0.661 | -12.902 | -0.04 |
| 15/02/16 | 3040.89 | 3034.07 | 0.806 | 7.629 | 0.25 |
| 16/02/16 | 3486.47 | 3484.00 | 0.803 | 3.273 | 0.09 |
| 17/02/16 | 3344.03 | 3343.58 | 0.815 | 1.265 | 0.04 |
| 18/02/16 | 3559.69 | 3552.03 | 0.818 | 8.478 | 0.24 |
| 19/02/16 | 3334.43 | 3336.77 | 0.775 | -1.565 | -0.05 |
| 20/02/16 | 3499.72 | 3495.93 | 0.771 | 4.561 | 0.13 |
| 21/02/16 | 3205.53 | 3191.29 | 0.740 | 14.980 | 0.47 |
| 22/02/16 | 3317.90 | 3322.82 | 0.712 | -4.208 | -0.13 |
| 23/02/16 | 3628.05 | 3623.49 | 0.764 | 5.321 | 0.15 |
| 24/02/16 | 3750.87 | 3751.18 | 0.786 | 0.476 | 0.01 |
| 25/02/16 | 2978.54 | 2973.45 | 0.833 | 5.923 | 0.20 |
| 26/02/16 | 3037.80 | 3033.65 | 0.786 | 4.936 | 0.16 |
| 27/02/16 | 3023.29 | 3022.72 | 0.749 | 1.319 | 0.04 |
| 28/02/16 | 3140.882 | 3141.25 | 0.764 | 0.394 | 0.01 |
| 29/02/16 | 3515.89 | 3511.69 | 0.803 | 0.803 | 0.14 |

Source: Onitsha 330/132kv Transmission Substation (PC&M dept), Transmission Company of Nigeria (TCN).
From table 1.3, the energy loss is calculated thus;
For 1/01/16,
Total energy loss = (3706.942 – 3710.030) + 0.663= -2.424
Therefore,

$$\text{Energy loss (\%)} = \frac{-2.424}{3706.942} \times 100 = -0.07\%$$

$$\text{Average Energy Loss in January (\%)} = \frac{\sum(\text{Energy loss})}{\text{No. of days}} \quad (1.5)$$

= -0.85/31
= -0.03%

$$\text{Average Energy Loss in February (\%)} = \frac{\sum(\text{Energy loss})}{\text{No. of days}}$$

= 4.18/29
= 0.14%

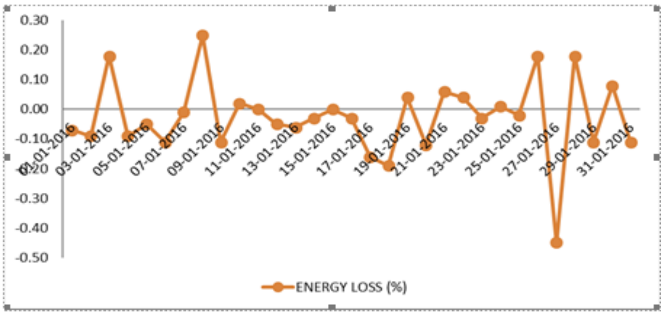


Figure 2; Daily energy loss (%) for the month of January, 2016 in Onitsha 330/132kv T/S

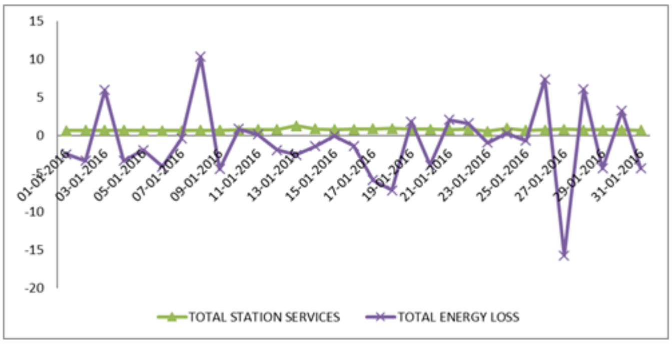


Figure 3; Insignificance of station service for January, 2016.

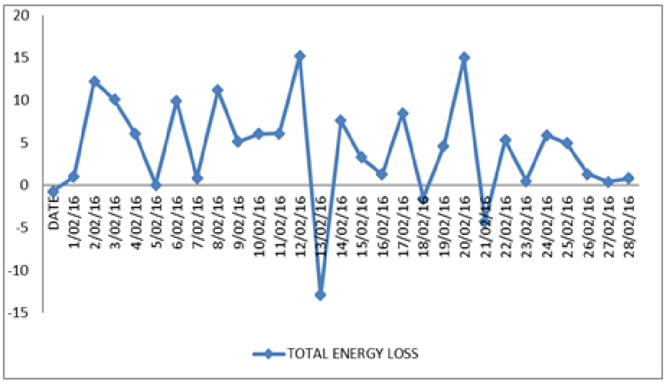


Figure 4: Total Energy loss for February, 2016

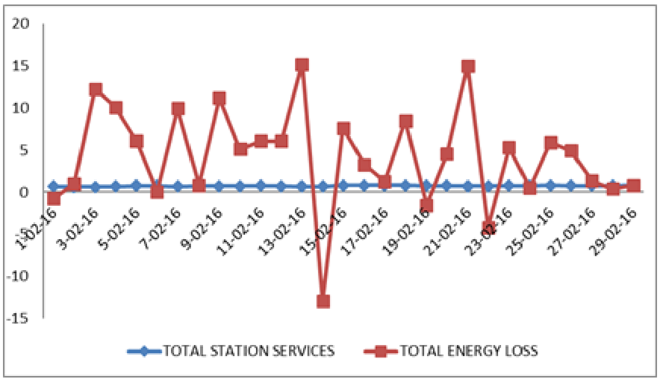


Figure 5; Insignificance of station service in energy loss for February, 2016

- **1.5 CONCLUSION**

The method used in this paper makes use of data collected from the 1st of January, 2016 to the 29th of February, 2016 from all transformers and feeders. By calculation the factors energy loss were calculated as shown in table 1.5;

Table 1.5: Summary of Energy Data

| | JANUARY | FEBRUARY |
|---|---|---|
| Maximum Energy Loss (%) | 0.25 | 0.64 |
| Minimum Energy Loss (%) | -0.11 | -0.64 |
| Average Energy Loss (%) | -0.03 | 0.14 |

Table 1.5 shows the calculated energy data. It summarizes the efficiency of the transmission substation as we have stated in the introduction that total system energy loss is a key indices used to know how efficient and effective power has been distributed in a transmission substation. The above data has shown that Onitsha 330/132kV transmission substation has been transmitting and distributing power efficiently and effectively. We can draw such conclusion on bases that the Transmission Company of Nigeria's energy loss bench mark is 8%. This could only have been achieved through efficient metering system, proper maintenance, quick response to failed equipment, regular annual maintenance on major equipment such as power transformers, circuit breakers, isolators, CVTs, CTs etc. there are draw backs as to why the transmission substation could not perform better and they are attributed to faulty energy meters, lack of spares and spare parts, unavailability of voltage transformers on associated feeders, ageing of instrument transformers, poor working condition for Engineers. Energy loss as much as possible has to be minimised and this can be achieved through efficient metering system, low equipment down time, proper maintenance of equipment and installation of voltage transformers on each feeder

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