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TECHNICAL POWER LOSSES EVALUATION IN ELECTRICITY DISTRIBUTION NETWORK

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Abstract

The electricity supply systems are characterized or prone to shortage of energy supply. These shortages are as a result of power losses in the power system. There are power losses in the generation system, transmission system, and distribution system and consumers' appliances. This paper evaluates technical power losses in some selected feeders in the Calabar 33kV distribution network of the Port-Harcourt Electricity Distribution Company (PHEDC) in Nigeria. The power losses in the power transformers and the distribution lines in each feeder were calculated for the year 2021 using the load and load loss factor. The study made it possible to know the feeder that contributes more or less to the power and energy losses in the system. For the study year; 2021, the Amika Feeder (feeder 9) contributed65.15% of the total power, energy and revenue losses followed by EPZ II feeder with 24.29%. It was discovered that these losses are due to poor maintenance and use of undersized cables/conductors used during repairs of cut sections of the feeders, ageing of the transformers and cables, excessive distribution feeder route, and overloading of transformers. The study proposed ways to reduce losses by regular inspection and monitoring, use of smart energy meters, replacement of undersized cables and expansion of distribution substations and installation of transformers closer to the load centers.

Keywords: Technical Power Losses, Non-Technical Losses, Energy Losses, Distribution Network, Load Loss Factor.

1.0 Introduction

Electric power produced at the generating plants gets to consumers through transmission system, transformers and distribution system. The distribution system network receives power supply from the transmission system network and distributes to consumers. The major number of losses in power system is in the primary and secondary distribution lines. In distribution system, there are distribution lines, transformers and other components across the length and breadth of the area to ensure reliable and efficient distribution of power supply to consumers. Where the area the distribution system is supplying power to be large, the distribution system network can be divided into different units called feeders. Many times, the power available to the consumers in each distribution feeder is less than the power such feeder receives. The difference represents losses (i.e., the amount of energy not paid for) in the system. These losses are wasteful energy contributed to by all the components of the distribution system network and cannot be recovered or accounted for, thus resulting in a shortage of electricity supply to customers. This could also lead to an inefficient and unreliable electricity supply system alongside load shedding, high operating cost, high revenue losses to utilities and consequently result to high cost of electricity (Omorogiuwa, et al 2015). Losses can be minimized using different methods as presented by Al-Mahroqi et al (2012). Among the methods presented by Al-Mahroqi et al (2012) includes feeder reconfiguration, distributed generation, VAR compensation and installation of smart meters. Aborishade et al (2014) applied static synchronous compensator (STATCOM) and static synchronous series compensator (SSSC) to reduce losses in the power network. Other approaches include the use of embedded core in a transformer as reported by Ganie et al (2014). However, before applying any method of reducing power losses, it is important to evaluate and know the amount of power losses in the power system, the energy losses due to the power loss over time, the loss of revenue involved and the percentage contributed by each component. This will further help in losses reduction, improvement in revenue and efficiency of the distribution system.

Technical power losses are analyzed using different methods such as the product of the square of current and resistance, differential power loss method, computing the line flow and line losses, the Depezo loss formula, analyzing system parameters, B-loss coefficient, load flow simulation and load loss factor (Anumaka, 2020).

This paper presents evaluation of technical power losses of selected feeders in the Calabar 33kV/11kV distribution network of the Port Harcourt Electricity Distribution Company (PHEDC) network using load loss factor method. Because the load varies with time of the day, applying this factor takes care of the fact that the current in a feeder is not at maximum all the time and at a particular time it is maximum while at other times it may be less than maximum.

2.0. Classification of power losses

Generally, there are two categories of losses in the distribution system; technical and non-technical losses. Technical losses occur as energy dissipated in all electrical equipment or components in the power system. Some of these components include conductors and equipment used in transmission lines, transformers and distribution lines as well as a measurement system. On the other hand, non-technical losses are losses that do not originate from the system components. These types of losses arise from commercial, administrative, electricity theft, and errors in electricity meter reading billing, faulty meters, and estimated billing (Komolafe, et al 2020). The technical losses can simply be grouped into variable and fixed losses.

2.1 Variable Losses

Usually, losses occur when current flows through resistive materials. Power system components and their parts such as transformer coils, aluminum or copper wires in transmission and distribution lines or cables and other components have internal resistances, which generate heat when current flows through them. These losses vary directly with the amount of current. To be specific, they are proportional to the square of the current flowing through the components of the power system, the resistance, length and cross-sectional area of the conductor or cables. Consequently, the higher the current flow, the higher the variable losses and vice versa. Losses in transmission networks are lower compared to distribution network because transmission network operates at higher voltages. At higher voltages, lower current is required to transmit the same amount of electric power. Conversely, distribution networks operate at lower voltages and are subject to a higher level of losses. Additional factors such as the effect of network imbalance, power factor and power quality can also have an impact on variable losses, as they influence the value of the currents flowing through conductors.

2.2 Fixed losses

These types of losses do not change with current, they occur in the form of noise and heat, experienced when electrical network components and equipment such as transformers are being energized. These losses are also known as no-load losses, because even if no power is delivered to consumers, the system apparatus has losses based on the fact that they are electrically energized. Fixed losses are commonly caused by no-load losses of a transformer, corona losses, as well as losses caused by the continuous load of measuring elements. It is well known that transformers' energizations are responsible for the major parts of the fixed losses (although this equipment also gives rise to variable losses). These losses occur in the transformers' core and are called 'core losses' or 'iron losses. Two types of core losses are known to exist: Hysteresis losses and Eddy current losses. Hysteresis losses are losses that stem from the reversal in magnetic polarity of the steel in transformer cores in every AC cycle. This causes the material to pulse (which emits a humming noise) and to heat up. 'Eddy current losses' are losses that stem from the circulation of induced currents in conducting parts that are not copper windings, such as the iron body or steel core of the transformer.

3.0 materials and method

The approach adopted for this study includes a collection of relevant documented information and data during a field trip to 33kV/11kV injection substations of the Port Harcourt Electricity Distribution Company (PHEDC), Calabar. The data collected are monthly maximum loading from January 2021 to December, 2021 of the four 33/11kV substations; Flourmill, Diamond Hill, EPZII and Amika as shown in Table 6. Other data include the line or feeder route length, the cross-sectional area and type of the conductor, and the type and rating of the power transformers shown in Table 7. Power is distributed to the various substations using a 150mm^2 aluminum conductor having a resistivity of $2.82 \times 10^{-8}\Omega$m. The collected data were used to compute the monthly power losses, energy losses and loss in revenue in the Calabar33kV distribution network within the period under study using the load and load loss factor.

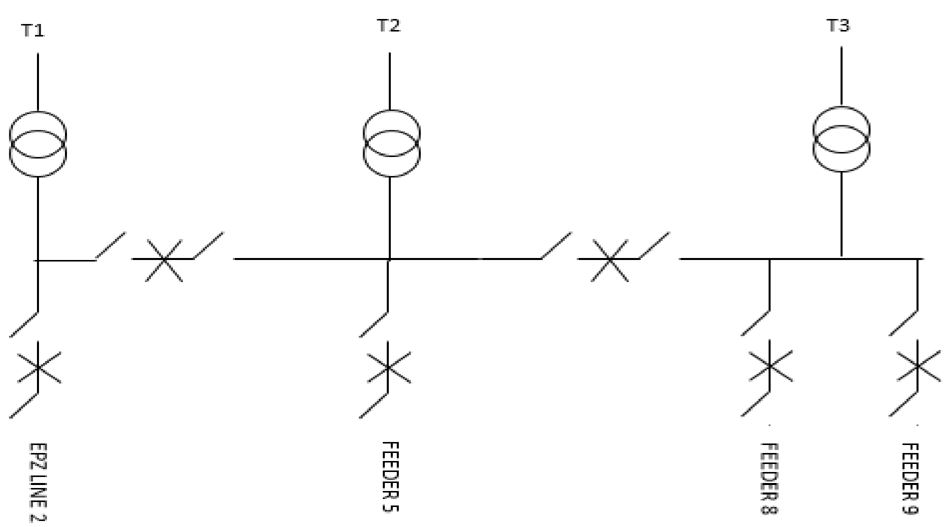

Fig.1: Selected feeders of the Calabar 33kV Distribution System Network.

Usually, the maximum current does not flow all the time in a feeder. It flows at a particular time of the day, month and year and at every other time, the current flow is less than maximum. In order to accommodate this situation, the load loss factor can be applied in the calculation of technical power losses and energy losses in distribution network. The Load Loss Factor (LLF) is defined as the ratio of the average power loss over a period of time (e.g., a day, a month or a year) to power loss at the time of peak demand within the same period given as;

$$LLF = \frac{Average\ power\ loss}{Power\ loss\ at\ peak} \quad (1)$$

The approximate value of the load loss factor (LLF) can be calculated from the load factor (LF) using equation (2) (Ademola & Ayokunle, 2016).

$$LLF = (k \times LF\ ) + (1-k)(LF)^2 \quad (2)$$

Where, LF is the Load Factor which is the ratio of the average demand to the maximum demand within the same period given by

$$LF = \frac{Average\ Demand}{Maximum\ Demand} = \frac{kVA_{AVG}}{kVA_{MD}} \quad (3)$$

And k is the coefficient of loading given by

$$k = \frac{Minimum\ kVA}{Maximum\ kVA} \quad (4)$$

The value of k can be 0.1, 0.2 or 0.3 depending on the subsystem of the power system network. For medium-voltage feeders and distribution substations, $k = 0.2$ is used while for the sub-transmission system, $k = 0.3$ is applied.

In order to evaluate the total losses in a distribution system network, the power losses in the power transformers, the distribution lines or cables as well as the power losses in the low voltage transformers must be known.

3.1 Total Losses in the Power Transformer

A transformer has two major components of power losses. There are losses in the laminated iron (core) and the copper (windings). The core loss is a no-load loss while copper loss is a non-load loss. The core loss occurs when the core is magnetized or energized, while copper loss occurs when current flows through the resistance of the primary and secondary windings of the transformer.

The total power loss in the power transformer P_{TFLoss}in kilowatt (kW) is given by

$$P_{TFLoss} = (P_{LLoss} + P_{NLLoss}) \times 10^{-3} \quad (5)$$

Where P_{LLoss} is the on-load power loss and P_{NLLoss} is the no-load power loss also known as iron loss (P_i).

The load power loss P_{LLoss} is related to the copper loss P_C and the load loss factor LLF as follows;

$$P_{LLoss} = P_C \times \left(\frac{kVA_{MD}}{kVA_{Ratig}}\right)^2 \times LLF \quad (6)$$

Where,P_C is the full load copper loss, kVA_{MD} is the maximum demand in a period, kVA_{Rating} is the kVA rating of the transformer. Substituting equation (6) into Equation (5), the total power losses P_{TFLoss} in the transformer become;

$$P_{TFLoss} = P_C \times \left(\frac{kVA_{MD}}{kVA_{Ratig}}\right)^2 \times LLF + P_{NLLoss}$$

$$P_{TFLoss} = P_C \times \left(\frac{kVA_{MD}}{kVA_{Ratig}}\right)^2 \times LLF + P_i \quad (7)$$

The values for P_C and P_i can be obtained from the transformertechnical specifications.

If there are more than one transformer in the distribution system, the total power losses in the transformers are the sum of all the losses in all the 33kV/11kV and 11kV/0.415kV transformers involved in the distribution system network.

3.2 Total losses on the distribution lines or feeder

The total power losses of a three phase distribution lines or feeders are given by

$$P_{LLoss} = 3(I_m)^2 \times R \qquad (8)$$

Considering the Load Loss Factor (LLF), equation (8) becomes;

$$P_{LLoss} = 3(I_m)^2 \times R \times LLF \qquad (9)$$

Where, I_m is the maximum current in amperes (A) flowing through the distribution lines and R is the total resistance of the conductor of the lines in ohms (Ω). When the resistance per unit length in kilometer is known, the total resistance R is also the product of the unit resistance $r\ (\frac{\Omega}{\text{km}})$ and the length of the conductor of the lines in the feeder. The maximum current I_m and the resistance R of the line are given in Equations (10) and (11).

$$I_m = \frac{P}{\sqrt{3}V\cos\theta} \qquad (10)$$

$$R = \frac{\rho L}{A} \qquad (11)$$

Where, P is the maximum power loading (kW or MW) on the feeder within the period (e.g. a day, month or a year), V is the linevoltage (V), $\cos\theta$ is the power factor (pf), ρ is the resistivity of the conductor of the line (Ωm), L is the length of the line (m or km), A is the cross-sectional area of the conductor (mm^2).

The total power losses on the feeder or distribution lines is obtained by substituting equations (2), (10) and (11) into equation (9) and expressed as,

$$P_{LLoss} = \frac{P^2\rho L}{3A(V\times pf)^2}(k \times LF) + (1-k)(LF)^2 \qquad (12)$$

Therefore, the total power loss in the distribution system is given as the sum of the power losses in the transformers and the distribution lines (feeders) as;

$$P_{TLoss} = P_{TFLoss} + P_{LLoss} \qquad (13)$$

The power losses on each feeder is calculated for a month using the monthly maximum and average power loading, the resistivity and cross sectional area of the conductor used for the distribution lines, and the distribution line or route length. Applying equations (10), (11), (2) and substituting into equation (9), an example of the power losses in the distribution line feeding Flourmill feeder for the month of May, 2021 is obtained using the data in Table 6 and Table 7 as follows;

$$I_m = \frac{8.3\times 10^6}{1.732\times 33\times 10^3\times 0.8} = 181.52A$$

$$R = \frac{2.82\times 10^{-8}\times 1\times 10^3}{150\times 10^{-6}} = 0.188\,\Omega$$

$$LF = \frac{7375}{8300} = 0.8886$$

$$LLF = 0.2\times(0.8886) + 0.8\times(0.8886)^2 = 0.80933$$

$$P_{LLoss} = 3((181.52A)^2 \times 0.188 \times 0.80933) = 15{,}044.75W$$

$$P_{LLoss} = 15.04kW \text{ or } 0.0150\text{MW}$$

The power losses in the transformer for the month of May, 2021 is

$$P_{TFLoss} = 75.6\times\left(\frac{10375}{15000}\right)^2 \times 0.80933 + 14.8$$

$$P_{TFLoss} = 44.07kW$$

Therefore, the total power loss on the Flour Mill feeder is obtained as

$$P_{TLoss} = 15.04kW + 44.07kW = 59.11kW = 0.05911MW.$$

The energy losses for the month of May with 31 days.

$$E_{TLoss} = 59.11kW \times 24hr \times 31 = 43{,}977.84kWh$$

And at the rate of N35:60k, the revenue losses for the month of May, 2021 will become,

$Rev_{TLoss} = 43{,}977.84kWh \times \text{N35: 60k} =$ N1,565,611.10k.

4.0. Results and discussion

The total power losses in the four selected feeders in the Calabar 33kV distribution system network was evaluated using the load loss factor technique. The monthly maximum power loading and the parameters of components in each feeder as shown in Table 6 and Table 7 were obtained during a field trip to the various 33kV/11kV substations. All the 33/11kV substations have two power transformers of rating as shown in Table 7 in the appendix. One transformer is energized at a time while the second is on standby. Table 1 shows the calculated values of the power losses (kW) on the feeders from January, 2021 to December, 2021 while Table 2 shows the breakdown of the losses that occurred in the transformers and feeder lines. The results in Table 2 show that the power losses in the feeder lines increase with the feeder. The losses in the Amika feeder and EPZII which has longer line route are greater compared to the losses in Flourmill and Diamond feeders with shorter line route. Table 3 shows the monthly energy losses (kWh) and the corresponding revenue losses in Table 4. The average monthly power losses were found to be highest in the Amika (Feeder 9) with a value of440.94kW followed by the EPZ II feeder with a value of 164.39kW. Similarly, the total energy losses on the Amika feeder for the year 2021 were 3,936,683kWh which is the highest followed by the total energy losses on the EPZ II feeder (1,467,681kWh) and Flourmill feeder (445,373.30kWh) while Diamond Hill feeder has the least total energy losses of 193,180kWh. The total power, energy and revenue losses of the selected feeders are 8.122MW, 6,042.92MWh and N215, 127,838.05k respectively. It can be seen that the utility company lost N215, 127,838.05k in 2021 due to technical power losses. This study also revealed that Amika feeder alone contributed 65.15% to the total losses that occurred in the four feeders.

Table 1: Calculated monthly power loss (kW) for 2021.

	Feeders			
Months	**EPZ Line 2**	**Flourmill (Feeder 5)**	**Amika (Feeder 9)**	**Diamond Hill (Feeder 8)**
JAN	158.58	48.145	272.82	18.16
FEB	158.58	53.93	340.67	21.27
MAR	172.13	49.085	340.67	19.66
APR	145.56	47.23	363.14	21.27
MAY	167.54	59.11	339.02	17.44
JUN	181.5	46.32	548.43	17.44
JUL	158.58	46.32	667.5	23.87

AUG	121.33	46.32	577.08	22.98
SEPT	191.14	51.94	287.78	27.71
OCT	191.14	48.145	591.67	25.75
NOV	149.82	48.145	435.03	19.3
DEC	176.79	53.93	527.43	24.8
TOTAL	1,972.69	598.62	5,291.24	259.65
AVG.	164.39	49.89	440.94	21.64

Table 2: Calculated Monthly Transformer and Line Losses (kW) for 2021.

MONTHS	EPZ II Feeder		Flourmill (Feeder 5)		Amika (Feeder 9)		Diamond (Feeder 8)	
	Transformer Losses (kW)	Line Losses (kW)	Transformer Losses (kW)	Line Losses (kW)	Transformer Losses (kW)	Line Losses (kW)	Transformer Losses (kW)	Line Losses (kW)
JAN	50.58	108	36.825	11.32	53.58	219.24	13.94	4.22
FEB	50.58	108	40.65	13.28	63.79	276.88	15.76	5.51
MAR	54.42	117.71	37.445	11.64	63.79	276.88	14.82	4.84
APR	46.91	98.65	36.22	11.01	67.17	295.97	15.76	5.51
MAY	53.12	114.42	44.07	15.04	63.54	275.48	13.52	3.92
JUN	57.07	124.43	35.62	10.7	95.02	453.41	13.52	3.92
JUL	50.58	108	35.62	10.7	112.92	554.58	17.28	6.59
AUG	40.05	81.28	35.62	10.7	99.33	477.75	16.76	6.22
SEPT	59.8	131.34	39.34	12.6	55.84	231.94	19.53	8.18
OCT	59.8	131.34	36.825	11.32	101.52	490.15	18.38	7.37
NOV	48.11	101.71	36.825	11.32	77.97	357.06	14.82	4.48
DEC	55.74	121.05	40.65	13.28	91.86	435.57	17.83	6.97
TOTAL	626.76	1345.93	445.71	142.91	946.33	4344.91	191.92	67.73
AVG.	52.23	112.16	37.98	11.91	78.86	362.08	15.99	5.64

Table 3: Calculated Monthly Energy Losses (kWh) for 2021.

	Feeders			
MONTHS	EPZ Line 2	Flourmill (Feeder 5)	Amika (Feeder 9)	Diamond Hill (Feeder 8)
JAN	117,983.50	35,819.88	202,978.10	13511.04
FEB	117,983.50	40,123.92	253,458.50	15,824.88
MAR	128,064.70	36,519.24	253,458.50	14,627.04
APR	108,296.60	35,139.12	270,176.20	15,824.88
MAY	124,649.80	43,977.84	252,230.90	12,975.36
JUN	135,036.00	34,462.08	408,031.90	12,975.36
JUL	117,983.50	34,462.08	496,620.00	17,759.28
AUG	90,269.52	34,462.08	429,347.50	17,097.12
SEPT	142,208.20	38,643.36	214,108.30	20,616.24

OCT	142,208.20	35,819.88	440,202.50	19,158.00
NOV	111,466.10	35,819.88	323,662.30	14,359.20
DEC	131,531.80	40,123.92	392,407.90	18,451.20
TOTAL	1,467,681.00	445,373.30	3,936,683.00	193,179.60
AVG.	122,306.80	37,114.44	328,056.90	16,098.30

Table 4: Calculated Monthly Revenue Losses (Naira) for 2021.

	Feeders			
MONTHS	EPZ Line 2	Flourmill Feeder 5)	Amika (Feeder 9)	Diamond Hill (Feeder 8)
JAN	4,200,213.312	1,275,187.728	7,226,019.648	480,993.024
FEB	4,200,213.312	1,428,411.552	9,023,121.888	563,365.728
MAR	4,559,104.032	1,300,084.944	9,023,121.888	520,722.624
APR	3,855,360.384	1,250,952.672	9,618,271.296	563,365.728
MAY	4,437,531.456	1,565,611.104	8,979,419.328	461,922.816
JUN	4,807,281.6	1,226,850.048	14,525,936.35	461,922.816
JUL	4,200,213.312	1,226,850.048	17,679,672	632,230.368
AUG	3,213,594.912	1,226,850.048	15,284,771.71	608,657.472
SEPT	5,062,610.496	1,375,703.616	7,622,256.192	733,938.144
OCT	5,062,610.496	1,275,187.728	15,671,208.29	682,024.8
NOV	3,968,192.448	1,275,187.728	11,522,378.59	511,187.52
DEC	4,682,530.656	1,428,411.552	13,969,721.95	656,862.72
TOTAL	52,249,456.42	15,855,288.77	140,145,899.1	6,877,193.76
AVG	4,354,121.368	1,321,274.064	11,678,824.93	573,099.48

Table 5: Summary of Power loss and Revenue Loss of each feeders for 2021.

Feeders	Power Loss (kW)	Energy Loss (kWh)	Revenue Loss (N)	% Revenue Loss (%)
EPZ Line 2	1,972.69	1,467,681.00	52,249,456.42	24.29
Flour Mill (Feeder 5)	598.62	445,373.30	15,855,288.77	7.37
Amika (Feeder 9)	5,291.24	3,936,683.00	140,145,899.1	65.15
Diamond Hill (Feeder 8)	259.65	193,179.60	6,877,193.76	3.20
Total	8,122.20	6,042,916.90	215,127,838.05	100

5.0 Conclusion

The power losses, energy losses and their corresponding revenue losses for the four selected feeders in the Calabar 33kV distribution network of the Port Harcourt electricity distribution network for the year 2021 were determined. The Amika feeder (feeder 9) contributed more than other feeders to the power losses, energy and revenue losses in the distribution system network. These losses are as a result of the long length of the feeder route, the excessive power demand from this feeder resulting in overloading, poor maintenance, overloading of transformers, aged distribution system components, and use of undersized cable during maintenances to replace the cut/damaged section of the feeder lines. Power losses cannot be totally eliminated but can be minimized. Reduction in power losses improves the reliability and availability of electrical power to consumers. In order to reduce power and energy losses, we recommend regular inspection and monitoring, maintenance, use of correct sizes of cables to replace cut cables, provision and upgrade of the distribution transformers on feeders with high losses. Above all, the study recommends the provision of modern supervisory and monitoring techniques to report the states of the distribution system components.

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Appendix

Table 6: Monthly Maximum and Average Loading (MW) on each feeder for 2021

MONTHS	FEEDERS			
	EPZ Line 2 (MW)	**Flourmill (Feeder 5) (MW)**	**Amika (Feeder 9) (MW)**	**Diamond Hill (Feeder 8) (MW)**
JAN	6.8	7.2	10.5	2.8
FEB	6.8	7.8	11.8	3.2
MAR	7.1	7.3	11.8	3
APR	6.5	7.1	12.2	3.2
MAY	7	8.3	11.77	2.7
JUN	7.3	7	15.1	2.7
JUL	6.8	7	16.7	3.5
AUG	5.9	7	15.5	3.4
SEPT	7.5	7.6	10.8	3.9
OCT	7.5	7.2	15.7	3.7
NOV	6.6	7.2	13.4	3
DEC	7.2	7.8	14.8	3.6
TOTAL	83	88.5	160.07	38.7
AVG.	6.92	7.375	13.34	3.23

Table 7: Parameters of the feeders and substations for 2021

	Feeders			
MONTHS	**EPZ Line 2**	**Feeder 5 (Flour Mill)**	**Feeder 9 (Amika)**	**Feeder 8 (Diamond Hill)**
Line Voltage	33kV	33kV	33kV	33kV
Power Factor	0.8	0.8	0.8	0.8
Cross Sectional Area of Conductor	$150mm^2$	$150mm^2$	$150mm^2$	$150mm^2$
Route Length	10km	1km	11km	2.8km
Resistivity of the conductor	$2.82 \times 10^{-8}\Omega m$	$2.82 \times 10^{-8}\Omega m$	$2.82 \times 10^{-8}\Omega m$	$2.82 \times 10^{-8}\Omega m$
Transformer Rating	7.5MVA	15MVA	15MVA	7.5MVA
Transformer Copper losses	38.3	75.6	75.6	38.3
Transformer Core losses	8.0	14.8	14.8	8.0