ANALYSIS OF COPPER LOSSES DUE TO UNBALANCED LOAD IN A TRANSFORMER
(A CASE STUDY OF NEW IDUMAGBO 2 x 15-MVA, 33/11-KV INJECTION SUBSTATION)

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ABSTRACT
This work investigates how distribution network ohmic losses can vary significantly with varying load unbalance. The analysis of distribution system losses is presented that considers balanced and unbalanced loads and their effect on the copper losses of a typical power distribution transformer. Load readings taken from all the public and private 11/0.415-kV transformers fed from the New Idumagbo Injection substation, 2X 15MVA, 33/11-kV were from EKO Electricity Distribution Company, Marina, Lagos. The result showed that the total transformer copper losses calculated for both balanced and unbalanced load for Adeniji Adele feeder is 3379701 units and 3490724 units respectively for the period (June 2012 and May 2013) under review. For Tokunboh feeder, 1660620 units and 1743982 units were obtained for both balanced and unbalanced loads respectively. Furthermore, the result also showed that the total transformer losses in Dolphin feeder amounted to 321555 units and 321993.8 units for both balanced and unbalanced load respectively. Comparison was made between the transformer copper losses calculated from the existing unbalanced load condition and the losses that would have resulted if the loads on the transformer were equally distributed between the phases. The result of these comparison shows that high levels of load unbalance produces greater losses in the distribution transformers when compared to balanced load. Therefore, copper losses of transformer vary considerably with the degree of load unbalance, hence reduction in the capacity of the transformer.

Keywords: *Substation, Transformer, Fault, Feeders.*

1. INTRODUCTION
Generally, three-phase balance is the ideal situation that any power system utility should achieve. However, single-phase loads, single-phase distributed resources, asymmetrical three-phase equipment and devices (such as three-phase transformers with open wye-open delta connections), unbalanced faults, bad connections to electrical connectors and many other factors cause power system imbalances and reduce power quality [1]. In a limited energy resource, energy efficiency is considered as a source of energy in a distribution system. This is particularly important in a country like Nigeria whose distribution system is faced with many problems, like low voltage drop and losses which vary with the pattern of loading in the distribution network [2]. Since utilities and consumers consider system losses as cost, its evaluation and reduction are necessary for researchers. There are many devices in distribution network responsible for energy losses, these include losses along distribution lines (feeders), losses in transformer windings and losses associated with unbalanced loads connected to distribution transformers.

2. AIM OF THE STUDY
Considering the importance of losses in a distribution system, the aim of this research is to evaluate losses in a distribution network due to unbalanced loading in a transformer and non-technical losses associated.

3. MATERIALS AND METHODS
The Idumagbo Injection Substation under review was visited and the following information (data) was collected:

1) Document containing the list of all 11-/0.415-kV transformers connected to the substation, year of manufacture, series number and ratings.
2) Single-line diagram of the substation and its associated feeders.
3) Load readings (red, yellow and blue phase) for each of the 11-/0.415-kV transformers in the network between June 2012 and May 2013.

The average load reading for the period under review and other data collected for the three feeders are presented in Tables 1.1 to 1.3.

Table 1.1: Substation parameters for Adeniji Adele 11-KV feeder

S/N	NAME OF SUBSTATION	Rating of transformer(KVA)	Average load current(A)			Total load current in the three phases
			Red Phase	Yellow Phase	Blue Phase	
1	PHASE 1-DOLPHIN ESTATE	500	343	401	456	1168
2	PHASE 2A-DOLPHIN ESTATE	500	352	394	363	1109
3	PHASE 2B-DOLPHIN ESTATE	500	406	235	295	936
4	PHASE 3-DOLPHIN ESTATE	500	330	298	387	1015
5	PHASE 4-DOLPHIN ESTATE	500	432	247	309	988
6	THOMAS-ADENIJI ADELE	500	179	413	319	911
7	GLOVER I-OSHODI	500	354	268	438	1060
8	GLOVER II-AMUTO	500	301	455	403	1159
9	OKEPOPO II-THOMAS	500	340	295	404	1039
10	GRIFITH-GRIFITH-OKEPOPO	500	213	172	150	535

Table 1.2: Substation parameters for Tokunboh 11-KV feeder

S/N	NAME OF SUBSTATION	Rating of transformer (KVA)	Average load current(A)			Total load current in the three phases
			Red Phase	Yellow Phase	Blue Phase	
1	TOKUNBO-ADAMS	500	236	427	385	1048
2	RICCA I-MACAULAY	500	308	351	459	1118
3	RICCA II-MACAULAY	500	264	370	455	1089
4	OMIDIDUN-EVANS	500	273	335	220	828
5	GRIFFITH-GRIFFITH I	500	221	229	423	873

Table 1.3: Substation parameters for Dolphin 11-KV feeder

S/N	NAME OF SUBSTATION	Rating of transformer(KVA)	Unbalanced Load Condition			
			Red Phase	Yellow Phase	Blue Phase	Total load current in the three phases
1	GRIFFITH II-OKEPOPO	500	237	419	440	1096
2	GLOVER II	500	378	271	406	1055
3	GLOVER I	500	198	311	298	807
4	PHASE III-DOLPHIN ESTATE	500	279	188	224	691
5	PHASE IV-DOLPHIN ESTATE	500	249	208	437	894

Mathematically, copper loss in a transformer is given by

Copper losses $= I^2R$ ----- (1.0)

Where I = current (A) and R = resistance of the transformer winding. There is, however, another type of copper loss created as a result of unbalanced currents flowing in a three-phase transformer. For a three- phase transformer, let the secondary load currents flowing in each of the three-phase be I_R, I_Y and I_B.

Thus, total load current $(I_T) = I_R + I_Y + I_B$ ------ (1.1)

Copper losses in each phase = I_R^2R (Red phase),

I_Y^2R (Yellow phase) and I_B^2R (Blue phase).

Where R is the winding resistance of the transformer per phase.

Therefore, Total copper loss (unbalanced load condition)

$= I_R^2R + I_Y^2R + I_B^2R = R(I_R^2 + I_Y^2 + I_B^2)$ ------- (1.2)

If the load on the transformer is balanced, then $I_R + I_Y + I_B = I$

Therefore, equation (1.2) becomes

Total copper loss $= R(I^2+I^2+I^2) = 3I^2R$ -------- (1.3)

Equation (1.3) gives the total copper losses in a transformer under balanced load condition, while equation (1.2) gives the total copper losses for unbalanced load.

Subtracting equation (1.3) from equation (1.2) yields:

$R(I_R^2 + I_Y^2 + I_B^2) - 3I^2R = P_{loss\ unbalanced\ load}$

$\therefore R\left[(I_R^2 + I_Y^2 + I_B^2\right] - 3I^2 = P_{loss\ unbalanced\ load}$ -------- (1.4)

Equation (1.4) shows that the total losses due to unbalanced load in a transformer would be higher as a result of unequal current flowing through the different phases of the transformer compared to when the load is balanced (equal current flowing through the phases). In determining these losses, the winding resistance per phase is assumed to be unity since this value is the same and constant for all phases of the transformer irrespective of the loading.

4. SAMPLE CALCULATION USING PHASE I-DOLPHIN ESTATE

A sample calculation using phase 1-Dolphin estate in Table 1.1 of the Adeniji Adele feeder is given below as:

For unbalanced load condition,

Red phase current (I_R) = 343

Copper loss in red phase = I_R^2 = 343^2 = 117649

Yellow phase current (I_Y) = 360

Copper loss in yellow phase = I_Y^2 = 360^2 = 129600

Blue phase current (I_B) = 415

Copper loss in blue phase = I_B^2 = 415^2 = 172225

For balanced load condition,

Current per phase (I) = $\frac{1118}{3} = 373$

Copper loss per phase = 373^2 = 139129

Total loss in the three phase = 3 x 139129 = 417,387 units

5. RESULTS AND DISCUSSION

The results from the copper losses calculations for both balanced and unbalanced load conditions show that:

i) The total transformer copper loss in the Adeniji Adele feeder is 3155081 units and 3167536 units for balanced and unbalanced load conditions respectively.

ii) The total transformer copper loss in the Tokunboh feeder is 1623256 units and 1627013 units for balanced and unbalanced load conditions respectively.

iii) The total transformer copper loss in the Dolphin feeder is 1607775 units and 1609969 units for balanced and unbalanced load conditions respectively.

iv) Copper losses in transformer vary considerably with the degree of load unbalance.

v) Unbalanced loading in a transformer will reduce the capacity of the transformer in a distribution system.

Table 1.4: Copper Losses For Adeniji Adele 11-KV Feeder

Copper Losses For Adeniji Adele 11-KV Feeder									
S/N	NAME OF SUBSTATION	Rating of transformer(KVA)	Unbalanced Load Condition				Balanced Load Condition		Net CU loss due to unbalanced load
			Total CU loss(Red Phase)	Total CU loss(Yellow Phase)	Total CU loss(Blue Phase)	Total loss in the three phases	Total CU loss(per phase)	Total loss in the three phases	
1	PHASE 1-DOLPHIN ESTATE	500	96721	160801	207936	465458	151580	454740	10718
2	PHASE 2A-DOLPHIN ESTATE	500	123904	155236	131769	410909	136653	409959	950
3	PHASE 2B-DOLPHIN ESTATE	500	164836	55225	87025	307086	97344	292032	15054
4	PHASE 3-DOLPHIN ESTATE	500	108900	88804	149769	347473	114469	343407	4066
5	PHASE 4-DOLPHIN ESTATE	500	186624	61009	95481	343114	108460	325380	17734
6	THOMAS-	500	32041	170569	101761	304371	92213	276639	27732

	ADENIJI ADELE								
7	GLOVER I-OSHODI	500	125316	71824	191844	388984	124844	374532	14452
8	GLOVER II-AMUTO	500	90601	207025	162409	460035	149253	447759	12276
9	OKEPOPO II-THOMAS	500	115600	87025	163216	365841	119948	359844	5997
10	GRIFITH-GRIFITH-OKEPOPO	500	45369	29584	22500	97453	31803	95409	2044

Fig. 1.1: Graph of balance and unbalance load for Adeniji feeder

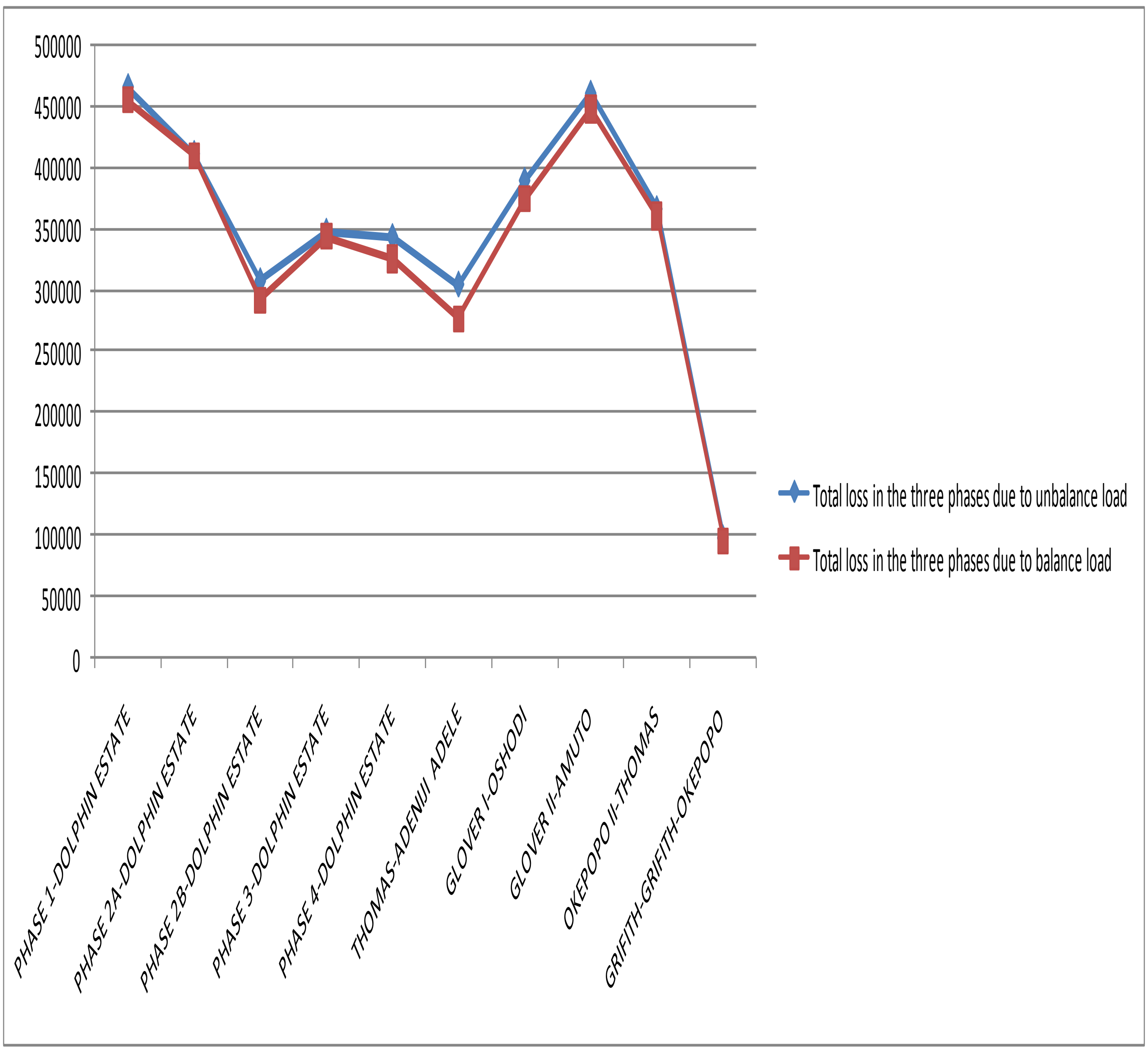


Table 1.5: Copper Losses For Tokunboh 11-KV Feeder

Copper Losses For Tokunboh 11-KV Feeder									
S/N	**NAME OF SUBSTATION**	**Rating of transformer (KVA)**	**Unbalanced Load Condition**				**Balanced Load Condition**		**Net CU loss due to unbalanced load**
			Total CU loss (Red Phase)	**Total CU loss (Yellow Phase)**	**Total CU loss(Blue Phase)**	**Total loss in the three phases**	**Total CU loss (per phase)**	**Total loss in the three phases**	
1	TOKUNBO-ADAMS	500	55696	182329	148225	386250	122034	366102	20148
2	RICCA I-MACAULAY	500	94864	123201	210681	428746	138880	416640	12106
3	RICCA II-MACAULAY	500	69696	136900	207025	413621	131769	395307	18314
4	OMIDIDUN-EVANS	500	74529	112225	48400	235154	76176	228528	6626
5	GRIFFITH-GRIFFITH I	500	48841	52441	178929	280211	84681	254043	26168

Table 1.6: Copper Losses for Dolphin 11-KV Feeder

Copper Losses For Dolphin 11-KV Feeder									
S/N	**NAME OF SUBSTATION**	**Rating of transformer(KVA)**	**Unbalanced Load Condition**				**Balanced Load Condition**		**Net CU loss due to unbalanced load**
			Total CU loss (Red Phase)	**Total CU loss(Yellow Phase)**	**Total CU loss(Blue Phase)**	**Total loss in the three phases**	**Total CU loss(per phase)**	**Total loss in the three phases**	
1	GRIFFITH II-OKEPOPO	500	56169	175561	193600	425330	133468	400404	24926
2	GLOVER II	500	142884	73441	164836	381161	123669	371007	10154
3	GLOVER I	500	39204	96721	88804	224729	72361	217083	7646
4	PHASE III-DOLPHIN ESTATE	500	77841	35344	50176	163361	53053	159159	4202
5	PHASE IV-DOLPHIN ESTATE	500	62001	43264	190969	296234	88804	266412	29822

Fig. 1.2: Graph of balance and unbalance load for Tokunbo feeder

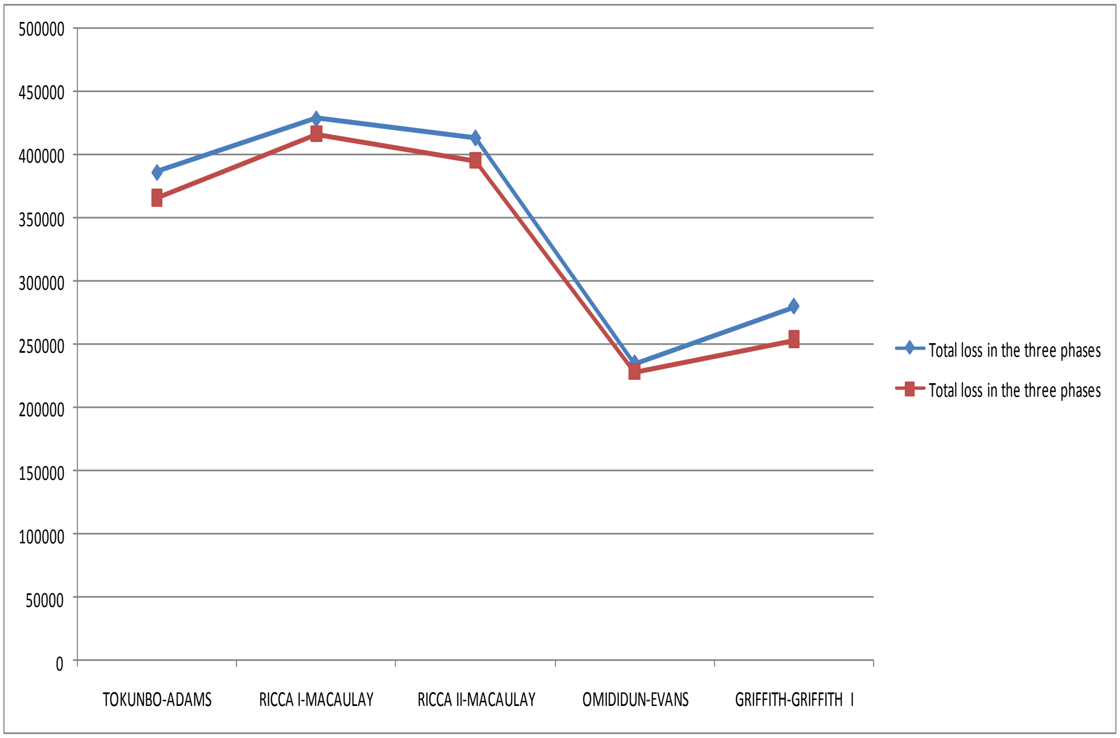
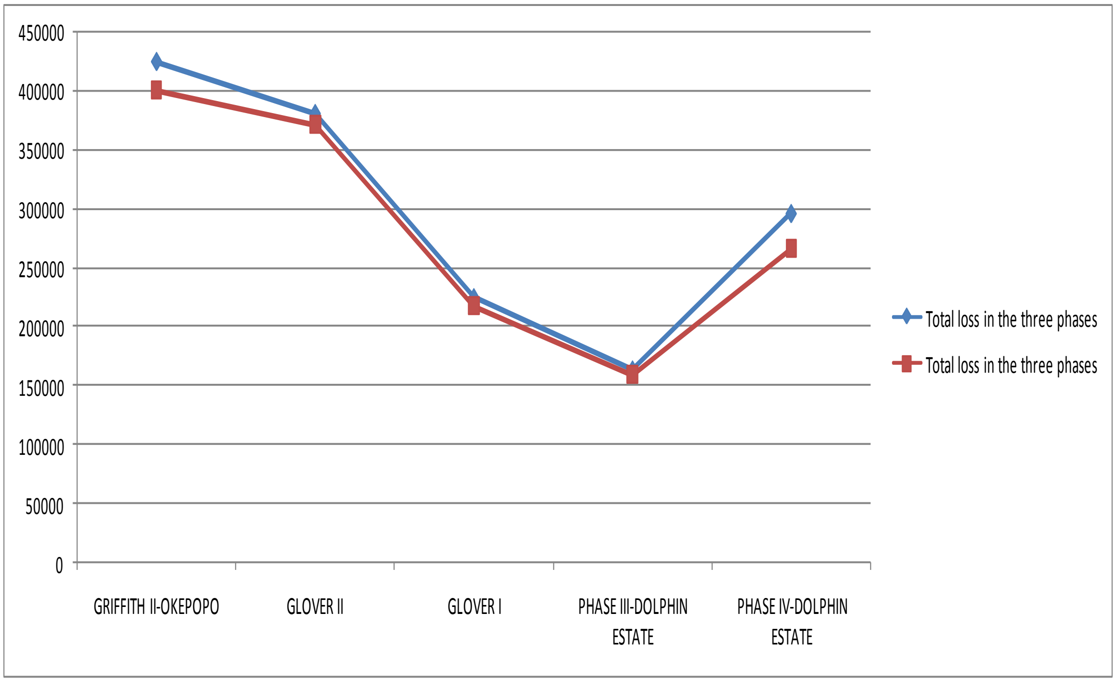


Fig. 1.3: Graph of balance and unbalance load for Dolphin feeder



6. CONCLUSION

This research project investigates the effect of unbalance load in copper losses of a distribution transformer. Also, loss evaluation in distribution systems considering both unbalanced load and balanced load scenarios in distribution transformers is also presented. The investigation shows that the average copper losses for both balanced and unbalanced load for Adeniji Adele feeder was 3379701 units and 3490724 units respectively. While for Tokunboh feeder, the average copper loss was 1660620 units and 1743982 units for both balanced and unbalanced load respectively. Furthermore, the average copper losses for Dolphin feeder was 321555 units and 321993.8 units for balanced and unbalanced load respectively. This means that network reconfiguration considering load balancing is highly required in order to diminish overall copper losses.

7. REFERENCES

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