FORMULATION OF PERMISSIBLE RADIAL DISTANCE BETWEEN DISTRIBUTION SUB–STATION AND RESIDENTIAL ELECTRICITY CONSUMERS

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ABSTRACT

One of the problems facing residential electricity power consumers in Nigeria is the effect of very low voltage at the consumers' terminals as a result of voltage drops on the distribution mains (low tension conductors) feeding them.

The consumers in the farthest distance to the supplying distribution substation usually experience low voltage as much as 100 volts as against a minimum terminal voltage of 216.2V or maximum voltage of 243.8V on a 230±6%V single phase system.

This paper therefore carried out a research to determine an average permissible radial distance between the substation and the last consumer on a distribution line, where the consumer's terminal voltage does not fall below 216.2V.

It came out with the following findings:

(a) That an Ammeter, Voltmeter and Energy meter be provided at every consumer's terminal, for load performance monitoring.

(b) That for a radial power distribution in residential areas, no load in excess of 20A per phase per house on a three-phase system, shall be connected.

(c) The distance between the substation and last house on the distribution mains shall not exceed 500 metres.

(d) The supply aluminium conductor per phase shall have a minimum of 70mm^2 cross–sectional area.

(e) The supplying transformer shall have a minimum of 500kva rating.

(f) The houses in the residential area may be a mixture of bungalow of 10 rooms or 2 flats and storey buildings of 4 flats

per plot of land excluding high-rise structures.

(g) *That when the total consumers load on a distribution line (mains) exceeds 160A/phase to a point where the voltage is 216V, then table 4 in the main text can be employed to calculate the necessary radial distance to the substation, by plotting a graph of current against distance. Thereafter the appropriate distance can be found for a given total load current. Obviously, such distance shall be less than 500 metres.*

With the adoption of the above measures, the consumers can:

- *Enjoy electricity in their homes with good working appliances.*
- *Reduce cost of power installation and consumption,*

The Power Holding Company of Nigeria Plc (PHCN) staff's job will greatly be simplified.

KEYWORDS: *Substation, voltage drop, radial distance, reduced cost of power, consumer.*

1.0 INTRODUCTION

It is very common in the distribution of electricity in rural and urban cities in Nigeria where houses are fed from a distribution substation transformer situated at more than 1000 metres away. The distribution lines feeding the houses are therefore usually affected by excessive voltage drop, thereby causing voltage supply at the consumer's terminals to be less than 216.2V. [1]

1.1 CAUSES

The main causes can be attributed to one or more of the followings:

(a) Pressure on Power Holding Company of Nigeria (PHCN) by consumer to get connected immediately a house is built.

(b) Staff of the PHCN not having a formulated data guiding them on maximum allowable distance between a consumer and a transformer.

(c) No periodical voltage drop monitoring on main distribution lines by PHCN.

(d) Insufficient distribution transformers, which are uniformly spread around the zone of distribution.

(e) Not-replaced burnt transformer, thereby necessitating an overloading of a nearby transformer.

(f) Underrated low-tension (L.T) distribution conductors feeding consumers. [1]

1.2 SOLUTIONS

In order to minimise excessive voltage drop on the mains, which consequently reduces, the consumer's terminal voltage level, the following measures had been in use with some deficiencies in application. [2]

(a) The provision of distribution transformers with tapping on high voltage windings.

(b) The provision of cables with adequate cross sectional areas to carry full load current.

(c) The provision of short cable runs, by locating substation transformers at the centre of gravity of the mains load.

With all the above measures in practice, residential areas still experience excessive low voltages at the consumer's terminal. In order to arrest this situation, this paper is written to assist PHCN staff and consumers by formulating a standard average distance allowable between the distribution transformer and the last consumer on mains conductors emanating from a feeder pillar. Such distance shall fall within the limits of an acceptable voltage drop, so as to enable the last consumer to have a minimum of 216.2V at its terminal.

The consumer's terminal voltage of 216.2V is chosen because that is the minimum voltage that will enable a subtraction of 4% of 216.2V (8.6V) in accordance with I.E.E. regulation, which gives a minimum voltage of 207.6V to be supplied to any element or appliance linked to a building electrical network. With a minimum voltage of 207.6V, the elements in a network will function properly. [2,3]

2.0 METHODOLOGY

2.1 ANALYSIS OF OLD MEASURES

(a) The First Method (TRANSFORMER TAP CHANGING): This varies from one country to another. The method is used to raise or reduce the voltage level along the mains so as to keep the consumer's terminal voltage level constant, with load fluctuations at different time of the day.

In Germany, the distribution transformers have tap changers on the high voltage sides, which can be used under off–voltage conditions only to vary high voltage. This will give a voltage variation on the low–voltage side of ±4% or ±5% of the rated voltage. The low voltage variation is 220±5%V. [2,3]

In Russia, distribution transformers of rating between 63–630kVA, with 6, 10, 20, 35kV have their voltages vary between ±10% of their nominal values. For the transformers of 1000–6300kVA with 20kV and 35kV have their voltage variations between ±9% of their nominal values. The low voltage variation is 220±10%V. [4]

In Britain, for low and medium voltage distribution transformers have their tap changers to vary voltages between ±6% of the nominal voltage. This is in accordance with the Electricity Supply Regulation of 1988. The low voltage rating is 240±6%V.

In Nigeria, the transformers are of foreign origin. The Power Holding Company of Nigeria Plc (PHCN), regulates the voltage on the mains so as give 230±6%V on single-phase supply. Any of the above transformers of foreign origin can accomplish that task i.e. varying the voltage between ±6% of the nominal value. Since the variation of output voltage is within the limit of 230±6%V, i.e. between 216.2V and 243.8V it shows that a maximum voltage drop of 27.6V is allowed on the mains when 216.2V is the terminal voltage of the last consumer from the sending end (the substation) which has a voltage of 243.8V. [5]

A voltage lower than 200V causes poor illumination at homes, poor performances of air–conditioner, fridge, hoover, ceiling fan and any element designed to operate on voltages between 200–240V. It is because of low voltages below 200V, consumers now adopt the usage of voltage stabilisers, which add to the cost of power installation and consumption at homes. [5,6]

(b) The Second Method (INCREASE OF CONDUCTOR SIZE): This is done by the use of standard aluminium stranded conductors of cross–sectional areas of 70mm^2 and 100mm^2 for low voltage supply. By this method, resistance of the conductor is maintained almost constant, when ambient temperature effect is ignored. Unfortunately, PHCN, which was formally called National Electric Power Authority (NEPA) always allow intending consumers to provide under rated mains aluminium conductors, poles, etc. for the distribution lines in practice, without considering the aftermath effect on consumers and the network.

(c) The Third Method (SHORT CABLE RUN): This is applicable in industrial or commercial area with heavy loads and not residential area with light loads. Despite all the above measures, residential areas in Nigeria still experience low voltages at the consumers' terminals due to poor technical planning and operations.

2.2 ANALYSIS OF THE NEW MEASURE

The new method proposed by this paper is aimed at combating the shortcomings associated with the technical planning and operations of power distribution mostly in densely populated residential areas with buildings not more than 4 flats per plot, by formulating a radial average distance between a distribution transformer and the last consumer on distribution mains, where voltage does not go below 216.2V, which serves as a reference voltage.

It excludes high-rise structures in residential zone.

It is worthy to note that the consideration of residential consumers was paramount here, because these consumers usually feel the effect of low voltage more than the industrial and commercial consumers who can afford to have personal distribution transformers located in their premises with short distances to cope with and good maintenance conditions.

2.3 PROCEDURE

Investigations were carried out in areas of three distribution substations in different locations in Benin City, which is a typical urban area of Nigeria. The survey took into account:

(a) The readings of load voltage and current consumption in every house connected to a unit in a distribution feeder pillar of 500kVA transformers via the distribution mains i.e. the low voltage four wire aluminium conductors of 3-phase supply.

(b) The types of building structures, which include a mixture of bungalows (2 flats) and storey buildings (4 flats) per plot.

(c) The area occupied by each building or house.

(d) The time of survey.

(e) The distance between the sub–station and every house.

(f) The size of aluminium conductors used.

The data collected are shown in tables 1 – 3.

3.0 RESULTS AND DISCUSSIONS

3.1 RESULTS

(a) Table 1: Pole Street Substation

In table 1, 216V is registered against a distance of 630m from the transformer for unit 1 of the feeder pillar. From the same transformer or substation, on Unit 2, the voltage of 216V is registered against a distance of 630m.

(b) Table 2: Godwin Abbey Substation

In table 2, 216V is registered against 470m on Unit 1 of the substation's feeder pillar. Also in table 2, on Unit 2, the voltage of 216V is registered against 500m.

(c) **Table 3: Stadium Road Substation**

In this table, on Unit 1, 216V is registered against 520m from the substation.

(d) 4 x 1 x $70mm^2$ Aluminium conductors were used, with 70^0C operating temperature and 30^0C ambient temperature.

(e) The supplying transformers were 500kva each, with 200A fused units in the feeder pillars.

3.2 DISCUSSIONS

- Finding the average distance in metres, from the 5 units of different three substations, we have 550m against a voltage of 216V. Therefore, an approximate distance of 500 metres can be recommended for a consumer terminal voltage of 216V (reference voltage).
- From tables 1, 2 and 3 and taking a given voltage of 216V as constant; then, the total current consumptions at 216V upwards of the consumers against the distances from each substation, shows that the higher the load, the nearer a consumer should be to the substation in order to avoid excessive reduced voltage at its terminal. This is shown in table 4, for load distribution against distances from the substations.

- A $70mm^2$ Aluminium conductor [3,4,5,6] fed from the 200A fuse in the feeder pillar has current rating of 191 Amps which is more than 160 Amps recorded for Godwin Abbey Substation in table 4. This is the highest value in the survey.

- $70mm^2$ Aluminium conductor has a volt drop/Amp/metre to be 0.96. With this value, maximum voltage drop to the last consumer with a maximum load of 20A at 500m is 9.6 volts. Adding 9.6 to 216 gives 226V < 230V.

  This is acceptable, because the substation voltage is 230V nominal [3,4,5,6].

- The maximum load in the survey was 20A on house 13 in table 3, which fell with in the reference voltage (216V) and substation voltage of 235V.

- The $70mm^2$ Al. conductor is suitable anywhere in Nigeria with a maximum ambient temperature of 33^0C.
- Ammeter and voltmeter are very necessary for load monitoring by the consumer and the PHCN staff, judging from the following reasons:

(i) With the voltmeter reading less than 216V, the PHCN staff is warned of the imminent danger to stop further connection of new consumers to the line thereby preventing excessive load and voltage drop.

(ii) With the ammeter and voltmeter, the consumer can choose for himself an equivalent generating plant to act as an emergency power source, having the knowledge of the present power consumption. Therefore, it is economically viable to have them at the consumer's terminal, when compared with their technical valuable functions.

4.0 CONCLUSION AND RECOMMENDATIONS

This paper, based on the results shown in tables 1, 2, 3 and 4 and the discussions above, therefore, concludes:

- That an Ammeter, Voltmeter and Energy meter be provided at every consumer's terminal, for load performance monitoring.
- That for a radial power distribution in residential areas, no load in excess of 20A per phase per house on a three-phase system, shall be connected.
- The distance between the substation and last house on the distribution mains shall not exceed 500 metres.
- The supply aluminium conductor per phase shall have a minimum of $70mm^2$ cross–sectional area.
- The supplying transformer shall have a minimum of 500kva rating.
- The houses in the residential area may be a mixture of bungalow of 10

rooms or 2 flats and storey buildings of 4 flats per plot of land excluding high-rise structures.

- That when the total consumers load on a distribution line (mains) exceeds 160A/phase to a point where the voltage is 216V, then table 4 in the main text can be employed to calculate the necessary radial distance to the substation, by plotting a graph of current against distance. Thereafter the appropriate distance can be found for a given total load current. Obviously, such distance shall be less than 500 metres.

It strongly recommends the points in items a, b, c, d, e, f and g to PHCN staff for future implementation so as to avoid excessive voltage drop at the consumer's terminal, thereby avoiding untold hardships experienced daily by electricity consumers in residential areas.

5.0 REFERENCES

1. Usifo, F. O. (1998), "Abolition of Bare Conductor Wiring in Developing Countries", J.E.E. Vol.3, No.2, pp. 76–83.
2. Gunter G. Seip (1979), "Electrical Installations Handbook", Vol. 1, Heyden and Son Ltd., Rheine, Germany, pp.17.
3. I.E.E. (1997), "Requirements for Electrical Installations, I.E.E. Wiring Regulations", 16th Edition, BSI and I.E.E, London, pp. 89.
4. Tihomirov P. M. (1968), "Design of Transformer", Moscow Energy Publishers, Moscow, pp. 235.
5. Raphael F. and Neidle M. (1974), "Electric Wiring of Buildings", Isaac Pitman and Sons Ltd., London, pp. 117.
6. Oria Usifo (2004), "Electrical Network Design and Installation in Building", Fredorus Ltd., Benin City, pp. 116–120.

TABLE 1 POLE STREET SUBSTATION

TIME 6pm - 8pm	HOUSE NUMBER	DISTANCE (M) OF HOUSE FROM TRANSFORMER	VOLTAGE (V) PER PHASE	CURRENT (A) PER PHASE	NUMBER OF FLATS	BUNGALOW (B) STORY (S)	AREA COVERED BY HOUSE $(M)^2$
			UNIT 1				
	1	25	240	5	2	B	250
	2	75	238	4.8	2	B	250
	3	130	236	6	2	B	500
	4	180	234	5.2	2	B	250
	5	240	230	5	2	B	250
	6	290	229	6.1	2	B	250
	7	350	227	9	4	B	150
$\xrightarrow{1}$	8	400	225	4	2	B	150
	9	460	220	4.4	2	B	250
	10	520	220	4	2	B	250
	11	580	218	8.8	4	B	250
	12	630	216	6	2	B	250
	13	690	210	4.6	2	B	250
	14	750	204	4.8	2	B	250
	15	800	200	5.6	2	B	250
	16	860	198	6.4	2	B	250
	17	910	197	4.4	2	B	250
	18	960	196	4.0	2	B	250
	19	1000	196	4.2	2	B	250
			UNIT 2				
	1	15	240	5.6	2	B	200
	2	70	240	6.2	2	B	500
	3	130	236	5.4	2	B	200
	4	190	234	4	2	B	100
	5	220	232	14	4	S	200
	6	270	229	15	4	S	300
	7	330	226	4	2	B	250
	8	380	222	4.2	2	B	250
	9	440	220	4.4	2	B	250
$\xrightarrow{2}$	10	500	219	3.6	2	B	150
	11	530	219	4	2	B	150
	12	570	217	4.8	2	B	250
	13	620	215	4.6	2	B	250
	14	630	216	4	2	B	250
	15	670	210	3.5	2	B	100
	16	700	208	3	2	B	100
	17	740	205	4	2	B	100
	18	790	204	3.2	2	B	100
	19	820	202	4	2	B	100
	20	870	200	4	2	B	250
	21	930	199	4.4	2	B	250

TABLE 2 GODWIN ABBEY SUBSTATION

TIME 6pm - 8pm	HOUSE NUMBER	DISTANCE (M) OF HOUSE FROM TRANSFORMER	VOLTAGE (V) PER PHASE	CURRENT (A) PER PHASE	NUMBER OF FLATS	BUNGALOW (B) STORY (S)	AREA COVERED BY HOUSE $(M)^2$
			UNIT 1				
	1	15	235	15	2	B	150
	2	50	234	16	2	B	100
	3	70	232	20	2	B	100
	4	100	230	18	4	S	400
	5	150	230	7	2	B	200
	6	220	228	13	2	B	250
	7	280	226	14	2	B	100
3	8	340	224	14	2	B	100
	9	390	222	15	4	S	500
	10	440	220	14.8	2	B	250
	11	470	216	13.2	2	B	250
	12	500	210	14	2	B	100
	13	530	210	10	2	B	100
	14	560	208	8	2	B	100
	15	600	205	6	2	B	100
	16	620	203	11	2	B	100
	17	650	200	15	4	S	250
	18	700	198	6	2	B	250
	19	760	196	10	2	B	250
	20	820	194	5	2	B	200
	21	860	190	6	2	B	200
	22	900	186	8	2	B	200
	23	950	182	3	2	B	150
	24	1000	180	4	2	B	100
	25	1040	176	5	2	B	100
			UNIT 2				
	1	10	240	15	4	S	400
	2	60	240	15	4	S	100
	3	120	238	4	2	B	150
	4	150	236	4.4	2	B	150
	5	190	234	4	2	B	150
	6	230	230	8.4	4	S	400
	7	280	229	4.2	2	B	150
4	8	370	224	4	2	B	100
	9	400	222	4	2	B	100
	10	420	220	5	2	S	250
	11	470	218	4	2	B	150
	12	500	216	4.4	2	B	150
	13	540	214	4.2	2	B	150
	14	580	212	4.4	2	B	150
	15	620	210	4.4	2	B	150

TABLE 3 STADIUM ROAD SUBSTATION

TIME 6pm - 8pm	HOUSE NUMBER	DISTANCE (M) OF HOUSE FROM TRANSFORMER	VOLTAGE (V) PER PHASE	CURRENT (A) PER PHASE	NUMBER OF FLATS	BUNGALOW (B) STORY (S)	AREA COVERED BY HOUSE $(M)^2$
			UNIT 1				
	1	10	235	5	2	B	250
	2	60	235	6	2	B	150
	3	90	235	6	2	B	150
	4	120	234	4	2	B	150
	5	160	232	8	2	B	150
	6	200	231	6	2	B	150
	7	245	230	4	2	B	200
	8	290	229	5	2	B	150
	9	320	227	7	2	B	100
	10	340	225	4	2	B	100
	11	370	223	10	2	B	150
	12	400	222	10	2	B	250
	13	440	221	20	4	S	250
	14	460	220	10	2	B	100
5	15	490	219	5	2	B	100
	16	520	216	7	2	B	100
	17	540	214	8	2	B	100
	18	570	212	4.4	2	B	100
	19	600	210	5	2	B	100
	20	630	208	6	2	B	150
	21	670	200	5	2	B	150
	22	700	198	6	2	B	150
	23	740	195	7	2	B	150
	24	770	192	7	2	B	400
	25	830	190	8	2	B	150
	26	860	187	20.2	4	S	250
	27	920	184	5	2	B	250
	28	970	180	25	4	S	500
	29	1060	176	30	4	S	500
	30	1160	172	31	4	S	500
	31	1240	170	11	2	B	250
	32	1300	160	5	2	B	250
	33	1360	155	4	2	B	250
	34	1420	150	6	2	B	200
	35	1470	140	10	2	B	400
	36	1540	135	6	2	B	200
			UNIT 2				
	1	15	230	4	2	B	225
	2	70	230	5	2	B	225
	3	120	228	4	2	B	250
	4	180	228	18	4	S	200
	5	250	226	11	4	S	250
	6	320	224	4	2	B	250
	7	380	222	5	2	B	250
	8	440	220	6	2	B	250
			UNIT 3				
	1	15	240	8	2	B	250
	2	90	235	5	2	B	250
	3	150	234	4	2	B	250
	4	200	232	10	2	B	150
	5	240	230	7	2	B	150
	6	270	228	5	2	B	250
	7	330	226	6	2	B	250
	8	400	224	7	4	S	250

TABLE 4 LOAD DISTRIBUTION

	Pole Street substation	Stadium Road Substation	Godwin Abbey Substation
Total load from the substation (A)	68.3	117	160
Distance of consumer (M)	630	520	470
Voltage at consumer's terminal (V)	216	216	216