POWER LOSS REDUCTION ON PRIMARY DISTRIBUTION NETWORKS USING TAP-CHANGING TECHNIQUE

Adejumobi I.A[1] & Adebisi O. I[2]
[1,2]Department of Electrical and Electronics Engineering, University of Agriculture, Abeokuta, Nigeria
Email: [1]engradejumobi@yahoo.com; [2]adebisi.oluwaseun@yahoo.com
Phone: +234703321545, +2348056712349

ABSTRACT

The quality of electrical energy reaching the electricity consumers via distribution system is very poor. Also, the management of electrical distribution system is becoming more complex and difficult because of various problems being faced on Nigeria Electricity Distribution System. These problems include; high power losses and voltage drops on the primary distribution networks. This work considered the application of tap changing transformer on primary feeders with the sole objective of minimizing distribution system losses. Piece-wise power equations to determine power loss and voltage drop are presented. To further reduce the losses, mathematical algorithms showing tap changing techniques were also presented with the basic assumption that voltage drop on any of the selected feeders should be within statutory limit of $\pm 10\%$. The algorithms were tested with three selected 11kV primary feeders; Odeda, Obantoko and Ibara feeders from Abeokuta Distribution Network in Ogun State, Nigeria. The results of Odeda and Obantoko 11kV feeders showed that the percent voltage drops are within the regulatory limit of $\pm 10\%$. However, with the application of optimum tap changing to Ibara feeder; it was still difficult to obtain a statutory limit of $\pm 10\%$ voltage drop. With this limitation, the proposed further study is to compare this technique with the use of shunt capacitor and appropriate reconfiguration techniques for distribution system.

Keywords: *Power loss, distribution network, tap changing, voltage drop, voltage regulation, optimization.*

1. INTRODUCTION

The Electric power system is a complex interconnection of generators, over-headlines, underground cables and transformers for the transmission and distribution of electric power over long distances from the power generating station to the consumers. Distribution system is the medium through which electric power is conveyed in bulk from the power station to the various end users [1]. It holds a very significant position in the power system since it is the main point of the link between bulk power and consumers, and it contributes to about 2-3% of the total losses in power systems [2]. In the entire power system, distribution losses account for the bulk of power system losses. Unlike in the transmission networks, distribution systems have high R/X ratio because $X > R$ in the distribution system [3]

Electrical and Electronic equipments are designed to operate on specified voltage, power rating and frequency. Deviation from the specified values poses serious threats to the entire power system. Power distribution system in Nigeria is characterized by high power and voltage losses which consequently lead to poor quality of electric power reaching consumers. Too wide variation of voltage may cause erratic operation or even malfunctioning of consumer's appliances. The main cause responsible for voltage variation is the variation in load on the supply system. Losses in distribution system are caused among others, by [4]

- Uneven distribution of loads among various feeders and substations
- Inadequate layout of feeders
- Overloading of distribution transformers.
- Poor power factor due to inadequate reactive compensation

Consumers are satisfied with quality and reliable electric power when the above mentioned factors are eliminated. This work considers the application of tap-changing transformer to minimize distribution system losses. The use of tap-changing transformer has the advantage of being able to regulate the voltage at a bus. With this approach, the appropriate tap settings required to compensate for the voltage drops in the distribution system are determined and hence, the power loss is minimized.

2. VOLTAGE REGULATION ON DISTRIBUTION TRANSFORMER

When power transformer is loaded at a loaded power factor, the secondary terminal voltage falls. Hence, to keep the output voltage constant, the primary voltage input must be increased. The rise in voltage from no-load to full-load at a given power factor expressed as a percentage of the rated voltage gives the voltage regulation of the transformer

[5]. For a distribution system power transformer, the voltage regulation is done at the secondary terminals using the step-voltage regulators that are attached to the secondary side of the transformer.

Once a load flow solution is obtained, the voltage regulation of any feeder is presented in equation (1) [6]:

$$Vreg = \frac{Vs-Vr}{Vr} \times 100\% \tag{1}$$

Where V_s is sending-end voltage
V_r is receiving-end voltage.

3. TAP CHANGING TRANSFORMER

The tap changing transformer is one of the important methods of voltage control and is usually employed where main transformer is necessary [4]. It works on the principle of regulating the secondary voltage based on changing of the number of turns on the primary or secondary. An increase in the primary turns, increases the emf per turn, and hence an increase on the secondary output voltage [4]. Standard distribution transformers have taps arranged in 2 ½% step so that the rated secondary voltage can be obtained when the primary supply voltage is 0, 2 ½, 5, 7 ½% below the nominal primary voltage rating [4]. The 2 ½% step can be used on transformers with automatic tap changing equipment.

The two types of tap changing include; off-load and on-load. The off-load tap changer is the cheapest method of changing the turns ratio of the transformer because the taps are changed when the transformer is disconnected therefore the required insulation for the contacts of the tap-changer is minimal. But this method does not ensure constancy of service thus it is not suitable for on-load voltage regulation. The on-load tap-changer regulates the power system voltage while the transformer is delivering load. It consists of a motor operated changer housed in an oil-filled compartment. Insulation requirement is higher thus it is more expensive.

4. OPTIMIZATION MODEL FOR LOSS MINIMIZATION

In the radial distribution system, each radial feeder is divided into load sections with a tap changing transformer at the beginning of the distribution network. However, there is the need to find the tap setting of the substation transformer that would give minimum distribution loss while satisfying the operating constraints under a certain load pattern. These operating constraints are voltage drop, current capacity and radial operating structure of the system.

The mathematical formulation for the minimization of power loss tap changer problems is presented in the literature in different ways. In this work, the problem formulation is presented in equation (2) [1]:

$$Minimize\ f = min(P_{T,Loss}) \tag{2}$$

$$P_{F,Loss} = \sum_{i=0}^{n-1} P_{Loss}(i) \tag{3}$$

Subject to the following constraints [7]:

- Radial network constraints
  The network must remain radial after reconfiguration
- Power source limit constraint
  The total loads of a certain partial network cannot exceed the capacity limit of the corresponding power source.
- Voltage constraint
  Voltage magnitude at each bus must lie with their permissible ranges to maintain power quality.

$$V_{min} \leq V_j \leq V_{max} \tag{4}$$

$$V_{drop(max)} \leq \pm 10\% \tag{5}$$

Where
i specifies branches between two nodes on the feeders;
j specifies nodes (buses) on the feeders;
$P_{T,Loss}$ is the total real power loss of the system;
$P_{Loss}(i)$ is the real power loss in the branch i;
V_j is Voltage magnitude of bus j;
V_{min} is the bus minimum voltage;
V_{max} is bus maximum voltage;
n is the total number of nodes on the feeder and the laterals.

Consider the representative component model depicted in figure1 below:

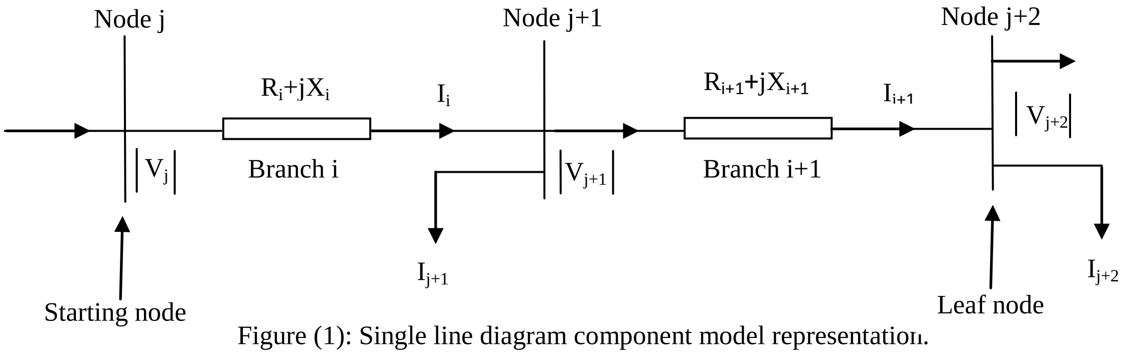

Figure (1): Single line diagram component model representation.

From the figure, V_j is the nodal voltage, I_i is the branch current and I_j is the load current in the node j.

Applying current analysis, we have equation (6) [8]:

$$I_i = I_{i+1} + I_{j+1} \tag{6}$$

Where;

I_i is current in branch i in amperes

I_{i+1} is the current in branch i+1 in amperes

I_{j+1} is the nodal injection current in node j+1 in amperes.

Assume initial voltage of 1 p.u. at all nodes on feeder and lateral that is V_j = 1p.u. for j = 1, 2,…,n where n is the total no. of nodes on feeder and laterals.

Starting from the root and moving towards the feeder and laterals, the nodal current injection at the node j is computed as equation (8) [9]:

$$I_j = \frac{S_j^*}{V_j} \tag{7}$$

Where;

I_j is the nodal current injection at node j in amperes

S_j is the load power at node j in MVA.

V_j is the assumed nodal voltage at the node j in kV.

The load power at node j is given by

$$S_j = P_j + jQ_j \tag{8}$$

Where;

$P_j = S_j\mathrm{Cos}\theta$ is the active load power at node j in MW

$Q_j = S_j\mathrm{Sin}\theta$ is the reactive load power at node j in MVAr

$\mathrm{Cos}\theta = 0.7$ is the assumed power factor for the distribution system

The nodal voltage at node j is obtained as [6]

$$V_j = V_{j+1} + Z_i I_i \tag{9}$$

Where;

V_j is the voltage value at node j in KV

V_{j+1} is the voltage value at node j+1 in kV taken into account the voltage drop

$Z_i = R_i + jX_i$ is the impedance of branch i in (Ω/km/phase)

I_i is the current in branch i in Amps.

From equation (9), the voltage drop between the nodes j and j+1 is computed as:

$$V_{drop\,(j,j+1)} = V_j - V_{j+1} = Z_i I_i \tag{10}$$

For optimal power loss, the equation (9) must be less than or equal to $\pm 10V_j$ [10].

The total active power loss and the corresponding total reactive power loss of the distribution system before tap changing are computed as [3]:

$$P_{LT} = \sum_{i=1}^{n} I_i^2 R_i \tag{11}$$

$$Q_{LT} = \sum_{i=1}^{n} I_i^2 X_i \tag{12}$$

Where;
P_{Lt} is the total active power loss in MW
Q_{Lt} is the total reactive power loss in MVAr
I_i is the magnitude of current in branch j in amps.
R_i is the resistance of branch i in (Ω/km/phase).
X_i is the reactance of branch i in (Ω/km/phase).
The total power loss of the distribution system is given as:

$$S = \sqrt{P_{Lt}^2 + Q_{Lt}^2} \text{ in MVA} \tag{13}$$

4.1. Application of Tap Changer

Consider a distribution system with a tap-changing transformer with "s" steps and with the tap variation of ±10% of the voltage selection as indicated in equation (9), the total voltage variation (TVV) is given by [11]:

$$TVV = 10\% - (-10\%) \tag{14}$$

$$TVV = 20\%$$
$$\text{TVV} = 0.2$$

Therefore, the per-unit voltage change per step is given by:

$$\Delta V_{(per\ step)} = \frac{0.2}{S} \tag{15}$$

Given that the base voltage of the distribution system is V_{base}, then, the exact voltage change per-unit step is given as;

$$\Delta V_{per\ step} = \frac{0.2}{S} V_{base} \tag{16}$$

Hence, for a distribution system with the base voltage V_{base} and with the tap changer on the secondary side, equation (16) gives the voltage change for each tap change.

The percentage voltage regulation provided by each of the taps of the regulating transformer is computed as equation (17).

$$\%V_{reg} = \frac{V_R - V_{base}}{V_{base}} \times 100 \tag{17}$$

Where V_R is the regulated voltage in kV.

If t denotes the tap position on the primary side of the regulating transformer, then, the regulated voltage at a given tap position t is given by equation (18).

$$V_R - V_{base} = \pm \frac{0.2}{S} t V_{base} \tag{18}$$

and

$$V_{R(per\ unit)} = 1 \pm \frac{0.2}{S} t \tag{19}$$

Subject to the assumption that the regulating transformer has an on-load tap-changer (OLTC) with variable taps in 32 steps in addition to the earlier assumption of $\pm 10\%$ voltage selection of the tap variation [10] then, S is considered to be 32. Hence, equation (15) becomes:

$$V_R = (1 \pm 0.00625t) V_{base} \tag{20}$$

Equation (17) with the application of equation (20) becomes:

$$\%V_{reg} = \pm 0.625t\% \tag{21}$$

Where t is the tap position, varying from 1 to 16.

Expressing the equation (21) in terms of T, the tap position expressed as a percentage of the regulated voltage, equation (20) becomes:

$$V_R = (1 \pm 0.01T) V_{base} \tag{22}$$

Where T = 0.625t with the positive sign implies regulation up while the negative sign implies regulation down. Equation (22) gives the regulated voltage at the source. Hence, the total voltage change for the tap changer is given by equation (23).

$$\Delta V = 0.01TV_{base} \tag{23}$$

For the primary distribution system, $V_{base}\ is\ 11kV$. Therefore, the voltage increment from the base value for any tap setting is given by equation (24).

$$\Delta V = 0.01T \times 11 \tag{24}$$

$$\Delta V \ = 0.11T \text{ in KV} \tag{25}$$

Hence,

$$V_{j\,(T)} = V_j + 0.11T \tag{26}$$

The total voltage drop on the radial distribution network is the algebraic sum of the individual voltage drops of the nodes, hence, mathematically:

$$\Delta V_{total} \ = \sum_{i=1}^{n} \frac{P_j\ R_{oi} + Q_j X_{oi}}{V_{j\,(T)}} \tag{27}$$

After the regulation, the regulated voltage at the source node becomes the updated nodal voltage. Hence, the nodal current injection at the node j at the regulated voltage becomes:

$$I_{j\,(T)} = \frac{S_j^*}{V_{j\,(T)}} \tag{28}$$

$$I_{j\,(T)} = \frac{S_j^*}{(1 \pm 0.11T)V_{base}} \tag{29}$$

From equation (29), the total active power loss and the corresponding reactive power loss at this new tap position T for the distribution are given by equations (30) and (31) respectively.

$$\mathrm{P}_{\mathrm{Lt\,(T)}} = \sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{I}_{\mathrm{i(T)}}^2 \mathrm{R_i} \tag{30}$$

$$\mathrm{Q}_{\mathrm{Lt\,(T)}} = \sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{I}_{\mathrm{i(T)}}^2 \mathrm{X_i} \tag{31}$$

Where;

$\mathrm{P}_{\mathrm{Lt\,(T)}}$ is the total active power loss after regulation in MW

$\mathrm{Q}_{\mathrm{Lt\,(T)}}$ is the total reactive power loss after regulation in MVAr

$\mathrm{I}_{\mathrm{i(T)}}$ is the magnitude of current in branch j in amps after regulation.

The total apparent power loss of the distribution after regulation is given as equation (32)

$$\mathrm{S_T} = \sqrt{\mathrm{P}_{\mathrm{Lt\,(T)}}^2 + \mathrm{Q}_{\mathrm{Lt\,(T)}}^2} \qquad \text{in MVA} \tag{32}$$

For the purpose of this work, in determining the optimal tap-setting of the distribution transformer for loss minimization, the following assumptions are made [10];

- The constant impedance transformer model is used that is, the transformer impedance does not vary with the position of the tap.
- The transformer has an on-load tap-changer (OLTC) with variable taps in 32 steps..
- The radial network with single source is considered.

5. SOFTWARE APPLICATION

The software to implement the work is developed from Visual Studios incorporating Visual Basic.Net. It is an object oriented programming language. The software is adopted principally because of the ease with which the user interacts and interprets the obtained results. The program is designed with Graphic User Interface that allows easy manipulation of data into developed software.

6. RESULTS AND DISCUSSION

The test samples for the analysis were the three loaded Primary Radial Feeders from the existing thirteen 11kV functioning feeders in Abeokuta Power Distribution Network, Power Holding Company of Nigeria (PHCN). The considered feeders are Ibara, Obantoko and Odeda, located within Abeokuta Metropolis and their loadings shown in table 1.

Table 1: Primary 11KV feeders

S/N	Name of 11kV feeder	Present MVA load	Length of the feeder (km)	Number of Nodes
1	Ibara	4.5	8	35
2	Obantoko	5.5	17	20
3	Camp	2.5	28	24

The maximum load at the nodes and distances between nodes were obtained from the Network layout of the Power Distribution Centre. The cable is 100mm^2 ASCR Aluminum conductor. Applying equations 1 to 12, voltage drops in kV and power losses are computed for each feeder. Also by considering the tap changing and applying equations 13 to 30, the power losses on each feeder were examined until the minimum voltage drop was obtained.

At the minimum voltage drop, the corresponding tap position which is considered to be optimum tapping position was noted and the corresponding power loss obtained.

Tables 2 to 5 were the results obtained for both pre-tap and tap conditions for the sampled data. From table 5, it is observed that by tap changing feeder's transformer, the voltage drops reduced by 0.3%, 0.1% and 2.5% for Camp, Obantoko and Ibara feeders respectively. Also, the power losses for the three feeders when applied tap changing was reduced by 13.2%, 10.81% and 21.81% for Camp, Obantoko and Ibara feeders respectively.

Table 2*: Result of the Optimal Tap Selector Program for Camp Feeder

Feeder Parameter		**Before Tap Changing**				**Before Tap Changing**			
NODE	**LOAD (MVA)**	**VOLTAGE (kV)**	**VOLTAGE DROP (kV)**	**ACTIVE POWER LOSS (MW)**	**REACTIVE POWER LOSS (MVAr)**	**VOLTAGE (kV)**	**VOLTAGE DROP (kV)**	**ACTIVE POWER LOSS (MW)**	**REACTIVE POWER LOSS (MVAr)**
1	0.3	10.90966	0.09034	0.02445	0.03092	11.53322	0.08553	0.02191	0.02772
2	0.3	10.86367	0.04599	0.01171	0.0148	11.48968	0.04354	0.01046	0.01322
3	0.3	10.84652	0.01715	0.00409	0.00517	11.47344	0.01624	0.00364	0.0046
4	0.8	10.82104	0.02547	0.00567	0.00716	11.44931	0.02412	0.00501	0.00634
5	0.2	10.80846	0.01258	0.00226	0.00285	11.43739	0.01192	0.00196	0.00248
6	0.2	10.78496	0.0235	0.00396	0.00501	11.41512	0.02227	0.00342	0.00432
7	0.6	10.77404	0.01092	0.00172	0.00218	11.40477	0.01035	0.00148	0.00187
8	0.1	10.76563	0.00841	0.00105	0.00133	11.39679	0.00798	0.00088	0.00111
9	0.1	10.76004	0.00559	0.00067	0.00085	11.39148	0.00531	0.00055	0.0007
10	0.5	10.73959	0.02046	0.00235	0.00297	11.37206	0.01942	0.00193	0.00243
11	0.5	10.73465	0.00493	0.00043	0.00055	11.36737	0.00469	0.00034	0.00043
12	0.05	10.72755	0.0071	0.00044	0.00056	11.36058	0.00679	0.0003	0.00038
13	0.15	10.72533	0.00222	0.00013	0.00017	11.35846	0.00212	9.00E-05	0.00011
14	0.2	10.72278	0.00254	0.00013	0.00017	11.35602	0.00244	8.00E-05	0.0001
15	0.5	10.71459	0.00819	0.00035	0.00044	11.3481	0.00791	0.00018	0.00023
16	0.2	10.82936	0.03431	0.00818	0.01035	11.45719	0.03249	0.00727	0.0092
17	0.3	10.70776	0.11328	0.02031	0.02568	11.34197	0.10734	0.01765	0.02231
18	0.5	10.65113	0.05663	0.00923	0.01167	11.2883	0.05368	0.00794	0.01004
19	0.3	10.72357	0.05047	0.00633	0.00801	11.35688	0.04789	0.00527	0.00666
20	0.3	10.71642	0.00715	0.00078	0.00099	11.35008	0.00679	0.00064	0.0008
21	0.1	10.74164	0.02399	0.00288	0.00364	11.37402	0.02277	0.00238	0.00301
22	0.5	10.72856	0.00609	0.00038	0.00048	11.36155	0.00582	0.00026	0.00033
23	0.05	10.72231	0.00444	0.00026	0.00033	11.35633	0.00425	0.00018	0.00022
24	0.05	10.69351	0.03182	0.00165	0.00208	11.32794	0.03052	0.00103	0.0013
		Total	0.6136	0.10942	0.13836	Total	0.58219	0.09484	0.11992
			Magnitude (MVA)	0.17639			Magnitude (MVA)	0.15289	

***Optimal Tap Point is 9**

Table 3*: Result of the Optimal Tap Selector Program for Obantoko Feeder

Feeder Parameter		**Before Tap Changing**				**Before Tap Changing**			
NODE	**LOAD (MVA)**	**VOLTAGE (kV)**	**VOLTAGE DROP (kV)**	**ACTIVE POWER LOSS (MW)**	**REACTIVE POWER LOSS (MVAr)**	**VOLTAGE (kV)**	**VOLTAGE DROP (kV)**	**ACTIVE POWER LOSS (MW)**	**REACTIVE POWER LOSS (MVAr)**
1	0.5	10.93961	0.06039	0.01396	0.01766	11.42339	0.05786	0.01282	0.01621
2	0.3	10.93225	0.00735	0.00151	0.0019	11.41634	0.00705	0.00137	0.00173
3	0.1	10.92551	0.00674	0.00127	0.0016	11.40989	0.00646	0.00115	0.00145
4	0.4	10.91245	0.01307	0.00239	0.00303	11.39736	0.01252	0.00216	0.00273
5	1.1	10.90103	0.01142	0.00185	0.00234	11.38642	0.01094	0.00165	0.00209
6	0.3	10.89415	0.00688	0.00071	0.0009	11.37983	0.0066	0.0006	0.00076
7	0.9	10.89189	0.00226	0.0002	0.00025	11.37766	0.00216	0.00016	0.0002
8	0.3	10.89016	0.00173	7.00E-05	9.00E-05	11.37599	0.00167	4.00E-05	5.00E-05
9	0.1	10.88737	0.0028	9.00E-05	0.00011	11.37327	0.00272	2.00E-05	3.00E-05
10	0.1	10.88576	0.00161	7.00E-05	8.00E-05	11.37166	0.00161	1.00E-05	1.00E-05
11	0.3	10.86013	0.07948	0.01626	0.02055	11.34723	0.07615	0.01481	0.01871
12	0.3	10.85944	0.07281	0.01373	0.01735	11.34657	0.06977	0.01243	0.01571
13	0.1	10.85991	0.05254	0.0085	0.01075	11.34702	0.05035	0.00759	0.00961
14	0.3	10.87764	0.02339	0.00241	0.00305	11.36399	0.02243	0.00204	0.00258
15	0.1	10.86355	0.01409	0.00123	0.00155	11.35048	0.01352	0.00101	0.00127
16	0.2	10.85833	0.00522	0.00043	0.00054	11.34546	0.00501	0.00035	0.00044
17	0.3	10.85217	0.00615	0.00043	0.00055	11.33956	0.00591	0.00034	0.00043
18	0.3	10.85692	0.03723	0.00325	0.00411	11.34411	0.03572	0.00266	0.00337
19	0.1	10.88325	0.00864	0.00036	0.00045	11.36933	0.00833	0.00021	0.00027
20	0.5	10.87088	0.01237	0.00045	0.00057	11.3574	0.01193	0.00024	0.0003
		Total	0.42617	0.06916	0.08743	Total	0.408679	0.06167	0.07795
			Magnitude (MVA)	0.11148			Magnitude (MVA)	0.09939	

***Optimal Tap Point is 7**

Table 4*: Result of the Optimal Tap Selector Program for Ibara Feeder

Feeder Parameter		**Before Tap Changing**				**Before Tap Changing**			
NODE	**LOAD (MVA)**	**VOLTAGE (kV)**	**VOLTAGE DROP (kV)**	**ACTIVE POWER LOSS (MW)**	**REACTIVE POWER LOSS (MVAr**	**VOLTAGE (kV)**	**VOLTAGE DROP (kV)**	**ACTIVE POWER LOSS (MW)**	**REACTIVE POWER LOSS (MVAr)**
1	0.5	9.15882	1.84118	1.29791	1.64101	10.4262	1.6738	1.07265	1.35621
2	0.5	8.89591	0.26291	0.17713	0.22387	10.18678	0.23942	0.14634	0.18496
3	3.8	8.85436	0.04155	0.02661	0.03372	10.14886	0.03792	0.02199	0.02786
4	0.1	8.80605	0.04831	0.01917	0.0242	10.10337	0.04549	0.01586	0.02003
5	0.85	8.75866	0.04739	0.0185	0.02335	10.05868	0.04469	0.01531	0.01933
6	0.5	8.62247	0.13619	0.04562	0.05769	9.9283	0.13038	0.03778	0.04778
7	0.8	8.58185	0.04062	0.01228	0.01553	9.88892	0.03938	0.01018	0.01287
8	0.3	8.54396	0.03788	0.00949	0.01199	9.85114	0.03778	0.00788	0.00995
9	2.05	8.50052	0.04345	0.01004	0.0127	9.80714	0.044	0.00833	0.01054
10	0.1	8.49779	0.00272	0.00034	0.00043	9.8028	0.00434	0.00026	0.00033
11	0.5	8.49384	0.00395	0.0005	0.00064	9.79581	0.00699	0.00037	0.00047
12	1.25	8.49302	0.00082	0.00016	0.0002	9.79296	0.00285	6.00E-05	8.00E-05
13	0.55	8.47816	0.01486	0.00083	0.00105	9.78423	0.00873	0.0005	0.00063
14	0.5	8.41216	0.066	0.00584	0.00739	9.74007	0.04416	0.00407	0.00515
15	0.2	8.33993	0.07223	0.00869	0.01099	9.68877	0.0513	0.00636	0.00805
16	0.5	8.70941	0.14495	0.05747	0.07264	10.01237	0.13649	0.04756	0.06011
17	1.8	8.54929	0.16012	0.05826	0.07366	9.86037	0.0152	0.04825	0.061
18	0.5	8.47835	0.07094	0.01745	0.02206	9.78929	0.07108	0.01451	0.01835
19	1	8.40923	0.06912	0.01478	0.01869	9.71797	0.07132	0.0123	0.01555
20	0.3	8.60274	0.15592	0.05223	0.06604	9.90941	0.14927	0.04326	0.0547
21	0.2	8.56603	0.03671	0.01159	0.01463	9.87401	0.03539	0.0096	0.01212
22	0.05	8.54669	0.01934	0.00584	0.00739	9.85527	0.01875	0.00484	0.00613
23	0.3	8.52762	0.01907	0.0057	0.00721	9.83675	0.01852	0.00473	0.00598
24	0.5	8.56669	0.01515	0.00379	0.0048	9.87381	0.01512	0.00315	0.00398
25	0.3	8.55417	0.01253	0.00274	0.00346	9.86097	0.01284	0.00227	0.00287
26	0.3	8.53039	0.01357	0.00314	0.00397	9.83739	0.01374	0.0026	0.00329
27	0.3	8.49779	0.00272	0.00034	0.00043	9.8028	0.00434	0.00026	0.00033
28	0.05	8.49666	0.00113	0.00018	0.00023	9.79984	0.00296	0.00012	0.00015
29	0.1	8.49579	0.00087	0.00016	0.0002	9.7971	0.00273	0.0001	0.00013
30	0.3	8.49463	0.00116	0.00043	0.00055	9.78937	0.00773	0.00024	0.00031
31	0.05	8.49351	0.00112	6.00E-05	8.00E-05	9.78857	0.00081	1.00E-05	1.00E-05
32	0.25	8.48972	0.00378	0.00016	0.0002	9.7869	0.00166	2.00E-05	2.00E-05
33	1	8.4795	0.01022	0.00025	0.00032	9.78516	0.00174	1.00E-05	1.00E-05
34	1.25	8.47391	0.01912	0.00107	0.00135	9.781773	0.01123	0.00064	0.00081
35	0.3	8.33486	0.07731	0.0093	0.01176	9.68517	0.0549	0.00681	0.00861
		Total	3.49493	1.87806	2.37443	Total	3.19386	1.54926	1.95873
			Magnitude (MVA)	3.02738			Magnitude (MVA)	2.49736	

***Optimal Tap Point is 16**

Table 5: Summary of the Power loss and Voltage drops in some Abeokuta feeders

Before Tap Changing				**After Tap Changing**				
Feeders	**Voltage drop (kV)**	**Percentage Voltage drop**	**Power loss (MVA)**	**Optimal Tap Position**	**Substation Transformer Secondary Voltage (kV)**	**Voltage drop (kV)**	**Percentage Voltage drop**	**Power loss (MVA)**
CAMP (ODEDA)	0.6136	5.58%	0.17639	Tap 9	11.661875	0.58219	5.29%	0.15289
OBANTOKO	0.42617	3.87%	0.11148	Tap 7	11.48125	0.40869	3.72%	0.09939
IBARA	3.49493	31.77%	3.02738	Tap 16	12.1	3.19386	29.04%	2.49736

The results of Odeda and Obantoko 11kV feeders showed that the percent voltage drops are within the regulatory limit of ±10%. However, even with application of optimum tap changing to Ibara feeder; it was still difficult to obtain a statutory limit of ±10% voltage drop.

7. CONCLUSION

The distribution systems are usually designed to operate at specified power capability and voltage level. Operating outside the allowable tolerances of these values affect the quality of power reaching the consumers of electricity. This work has considered the application of tap changing transformer to regulate voltage on primary distribution feeders for the purpose of reducing power losses on the selected feeders. Three of the primary feeders in Abeokuta in Ogun state have been used as the test sample for the developed algorithm from the adopted power equations. These feeders are Camp (Odeda), Obantoko and Ibara. The results of Odeda and Obantoko 11kV feeders showed that the percent voltage drops are within the regulatory limit of ±10%. However, even with the application of optimum tap changing to Ibara feeder; it was still difficult to obtain a statutory limit of ±10% voltage drop.

This limitation of this technique is an indication that some other scientific methods need to be incorporated to achieve optimal power flow or minimum power losses on distribution networks especially heavily loaded ones. This challenge has attracted the attention to continue this work with a comparison study of the tap changing technique with the application of shunt capacitors and reconfiguration of the distribution network to achieve optimal loss reduction.

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