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Methodology for Evaluation of Aggregate Technical, Commercial and Collection (ATC & C) Losses in a Typical Radial Distribution System

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Abstract: *Radial system is the most common type of distribution system in developing countries of the world with inherent losses along the line. Aggregate Technical, Commercial and Collection (ATC & C) Losses as an index to indicate losses in the power system is trendy as it provides clear picture of both energy and revenue loss conditions. This paper presents a pragmatic feeder-wise methodology for establishing Aggregate Technical, Commercial and Collection (ATC & C) losses in a typical Nigerian distribution system. The case chosen for this study is an area covered by Life Camp Area Office of Abuja Electricity Distribution Company (AEDC) of Nigeria. The analysis was achieved through extensive field survey and critical study of the schematic diagram of the network area. This study, of course, serves as a working tool to seasoned fieldworkers and utilities when appraising distribution system losses.*

Keywords: *Radial System, ATC & C losses, Power system losses, Billing Efficiency, Collection Efficiency*

1. Introduction

Electrical distribution is the last stage in the delivery of electricity to consumers. The distribution system conveys electricity from the transmission network to consumers through distribution transformers. It is the feeblest tie in the power sector value chain, and the most opened to the critical observation of its users. While power generation sub-sector is struggling to meet up with increasing demands, the distribution sub-sector has been reeling under losses [1]. Power system losses are wasteful energies due to internal or external factors that are dissipated in the system. Radial distribution system has only one source of power for group of electricity consumers. Its network leaves the substation and passes through the network area with no usual connection to any other supply [2]. No matter how carefully the power system is designed, losses are inevitable. Therefore, evaluation of these losses is of paramount importance. If there is a genuine baseline for computation of these losses, utilities can take steps to limit or minimise them, and this will lead to gross reduction in the cost of operations and consequently, gross reduction in the cost of electricity to consumers. Aggregate Technical and Commercial (AT & C) losses is the appropriate index used in a situation where the system is associated with losses which occur due to various reasons [3], [4]. AT & C losses are the difference between energy injected into the system and the energy for which payment is made. It is the aggregate of the Transmission and Distribution (T and D) losses and loss due to non-realization of payable demand [5]. In Nigeria, as contained in [6], the concept is referred to as Aggregate Technical, Commercial and Collection (ATC & C) losses. ATC & C losses were adopted by Nigerian Electricity Regulatory Commission (NERC) during the Nigerian Electricity Distribution Companies privatisation in the year 2013 as one of the criteria for identifying the most preferred bidders. That is, the buyers with the most aggressive but feasible ATC & C loss reduction trajectory over a 5-year period were considered. Notwithstanding, it is hoped that in this paper, various feeders in the network area and their nomenclatures will be identified, energy import and export points of the network area will be established and a methodology for evaluating losses of the network under study using the index ATC & C losses will be developed.

2. ATC & C LOSSES

ATC & C losses can be defined as the sum total of technical losses, commercial losses and shortage due to inability to collect total billed amount [7]. ATC & C losses comprise three elements, viz, technical losses, commercial losses, and collection losses. Technical losses occur due to inherent properties of the equipment used for transmission and distribution of electricity. Commercial losses occur when the billing process fails to capture all billable energies. And collection losses are the worst and most annoying. That is, the utilities failed to recover revenues in consonance with the billed energy [8]. Therefore, the aggregate technical, commercial and collection losses shall be computed using the formula [5], [9], [10];

ATC & C losses in %, δ = {1 - (Collection Efficiency × Billing Efficiency)} (1)

where,

Billing Efficiency, $\beta = \dfrac{Total\ energy\ billed\ of\ the\ network\ area}{Total\ input\ energy\ of\ the\ network\ area}$

Collection efficiency, $\omega = \dfrac{\mathrm{Re}\,venue\ collected\ of\ the\ network\ area}{Billed\ amount\ of\ the\ network\ area}$

Prerequisites for Evaluation of ATC and C Losses

Before ATC and C Losses of a network area can be evaluated, certain pre-requisites have to be met such as ring-fencing of electrical network area, metering of energy import/export points of the network, segregation of rural loads within the electrical network of area office, metering of distribution transformers, and metering of all the consumers within the electrical network of the area office. The billing and revenue collection system should be able to provide data like sales, energy billed and revenue collections for the whole network area. The billing system should be designed in a way that sales can be extracted for 33kV, 11kV feeders or for service centres as whole. These data may include sales which may have occurred outside the network area [9].

3. MATERIALS AND METHODS

A typical radial distribution system was explored through comprehensive field survey and critical study of the schematic diagram in order to identify various feeders and energy import and export points of the network area. The outcome of the field study was analysed to derive the methodology for evaluating ATC & C losses.

Description of the Case Study: The case chosen for this research is an area covered by Life Camp Area Office of Abuja Electricity Distribution (AEDC), Abuja. The network area has both 11kV and 33kV feeders with various configurations. Thus, feeder importing and exporting energy (Life Camp Feeder), feeders originating from and terminating within the network area (2.5 Feeder, 7.5 Feeder, Jiwa Feeder and Gwagwa Feeder), feeders originating and exporting energy from the network area (11kV Dei-Dei Feeder), and feeders importing energy and terminating within the network area (L33 feeder, Line Breaker Feeder, H37 feeder, 33kV Dei-Dei feeder, 5B Feeder, and 7A Feeder). The 33kV Dei-Dei feeder however, was provided for redundancy. It was usually used to convey power to the network area in the event L33 feeder was out of operation on major maintenance or prolonged faults. Figure 1 shows the periphery of the network area under study.

4. ANALYSIS OF FEEDERS IN THE NETWORK FOR COMPUTATION OF ATC AND C LOSSES.

4.1. Computation of Input Energy

If $M_i(i = 1,2,3,4,....n)$ represents boundary meters recording energy input to the network, $N_j(j = 1,2,3,4,....n)$ represents boundary meters recording export of energy, and n = number of feeders with boundary meters in the network.

Then the total energy received in the network is;

$$E_{in} = \sum_{i=1}^{n} M_i \tag{2}$$

Total energy exported from the network

$$E_{out} = \sum_{j=1}^{n} N_j \tag{3}$$

Net input energy of the network is given by; $\gamma = E_{in} - E_{out} = \sum_{i=1}^{n} M_i - \sum_{j=1}^{n} N_j$ (4)

4.2. Computation of Sales

The billing system recommended in this work is sales of energy obtained at feeder levels. Therefore, certain computation against mixed feeders shall be required because only sales against customers within the network under study shall be required for computation of total energy sales and revenues collection.

1) *Energy Billed on Feeders Originating from and Terminating within the Network Area*:

Energy billed on feeders originating from and terminating within the network area is given by:

$$P_{N1} = \sum_{x=1}^{n} P_x + \sum_{y=1}^{n} P_y \tag{5}$$

where,

$P_x(x = 1,2,3,4,....n)$ = Energy billed on feeders originating from and terminating within the network area for metered consumers, and

$P_y(y = 1,2,3,4,....n)$ = Energy billed on feeders originating from and terminating within the network area for unmetered consumers.

There are twelve (12) feeders radiating in the network. Their nomenclatures were used to designate the relationships in evaluating ATC and C losses outlined in the following subsections.

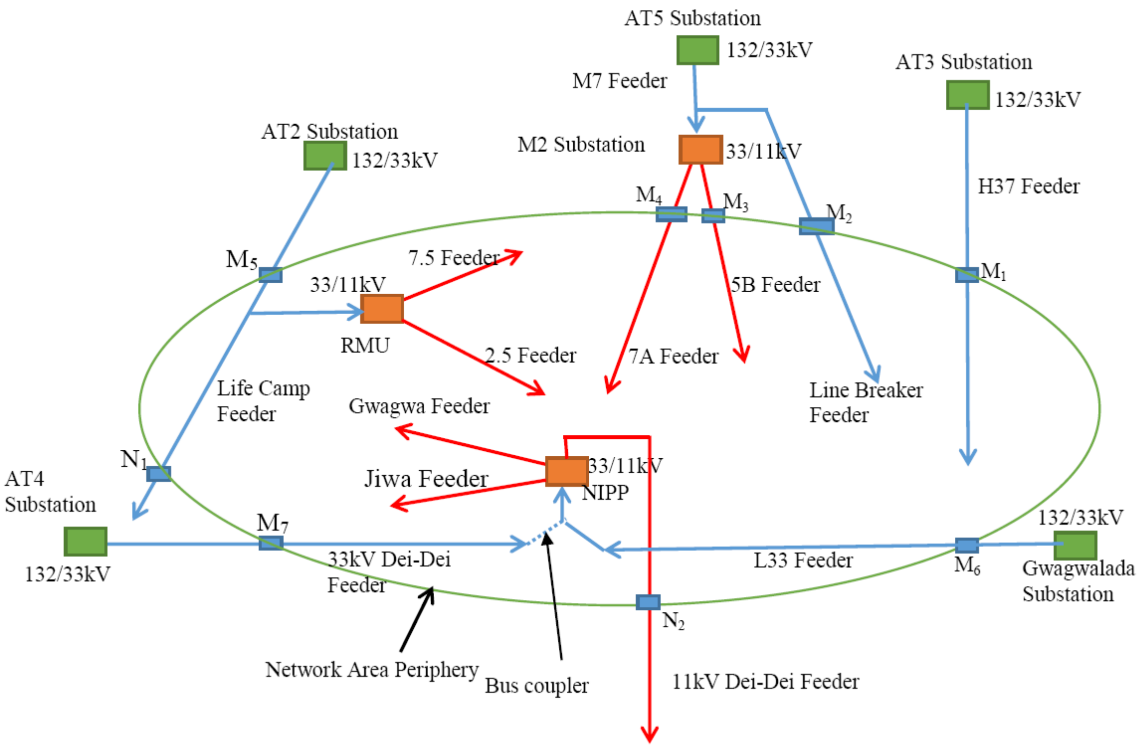

Figure1. *AEDC Life Camp Area Office Network Periphery*

2) *Energy Billed on Feeders Importing and Exporting Energy from the Network Area*

Apart from Life Camp feeder supplying power within and outside the network area at its voltage level of 33kV, it is also the source of 2.5 feeder and 7.5 feeder through RMU injection substation. The total energy sales on Life Camp Feeder for metered and unmetered consumers is therefore represented by;

$$P_{LC} = P_{F2.5} + P_{F7.5} + P_{LO} + P_{LI} \tag{6}$$

where,

$P_{F2.5}$ = Energy sales on 2.5 feeder for metered and unmetered consumers

$P_{F7.5}$ = Energy sales on 7.5 feeder for metered and unmetered consumers

P_{LO} = Energy sales on Life Camp Feeder at its voltage level of 33kV outside the network area (export of energy) for metered and unmetered consumers.

P_{LI} = P_{N2} = Energy sales (billed) within the network area on feeder importing and exporting energy (i.e. Life Camp Feeder at its voltage level of 33kV) for metered and unmetered consumers.

Therefore, equation (6) can be expressed as;

$$P_{N2} = P_{LC} - P_{F2.5} - P_{F7.5} - P_{LO} = \sum_{f=1}^{n} P_f + \sum_{g=1}^{n} P_g$$

where,

$P_f\left(f = 1,2,3,4,....n\right)$ = Energy sales within the network area on feeder importing and exporting energy for metered consumers,

$P_g\left(g = 1,2,3,4,....n\right)$ = Energy sales within the network area on feeder importing and exporting energy for unmetered consumers, and

P_{N2} = Energy billed on feeders importing and exporting energy from the network area.

3) *Energy Billed on Feeders originating from the Network Area but also Exporting Energy.*

This can be computed using equations (7), (8) and (9).

$$P_{TE} = \sum_{h=1}^{n} P_h + \sum_{i=1}^{n} P_i \tag{7}$$

$$P_{OE} = \sum_{j=1}^{n} P_j + \sum_{k=1}^{n} P_k \tag{8}$$

$$P_{N3} = P_{TE} - P_{OE} \tag{9}$$

where,

P_{TE} = Total energy sales (within and outside) on feeders originating from the network area but exporting energy.

P_{OE} = Energy sales outside the network area on feeders originating from the network area but exporting energy.

P_{N3} = Energy billed (sales) within the network area on feeders originating but exporting energy from the network area

$P_h\left(h = 1,2,3,4,....n\right)$ = Total energy sales on feeders originating from the network area but exporting energy for metered consumers.

$P_i\left(i = 1,2,3,4,....n\right)$ = Total energy sales on feeders originating from the network area but exporting energy for unmetered consumers.

$P_j\left(j = 1,2,3,4,....n\right)$ = Energy sales outside the network area for metered consumers on feeders originating from the network area but exporting energy.

$P_k(k = 1,2,3,4,....n)$ = Energy sales outside the network area for unmetered consumers on feeders originating from the network area but exporting energy.

NOTE: Considering the network under study, the only feeder with this attribute is 11kV Dei-Dei feeder.

4) Energy Billed on Feeders that import Energy and Terminate within the Network Area

Here, certain computation needs to be done. Referring to Figure 1, L33 feeder supplies the NIPP injection substation from which Jiwa, Gwagwa and 11kV Dei-Dei feeders emanate. 11kV Dei-Dei feeder has its source within the network, and also supplies power within and outside the network.

The total energy sales on L33 feeder for metered and unmetered consumers is,

$$P_{LT} = P_J + P_G + P_{DI} + P_{DO} + P_{L33} \quad (10)$$

P_J = Energy sales on Jiwa feeder for metered and unmetered consumers

P_G = Energy sales on Gwagwa feeder for metered and unmetered consumers

P_{DI} = Energy sales on 11kV Dei-Dei feeder inside the network area for metered and unmetered consumers.

P_{DO} = Energy sales on 11kV Dei-Dei feeder outside the network area for metered and unmetered consumers

P_{L33} = Energy sales on L33 Feeder at its voltage level of 33kV within the network area for metered and unmetered consumers.

Re-arranging equation (10);

$$P_{L33} = P_{LT} - P_J - P_G - P_{DI} - P_{DO}$$

NOTE: L33 feeder at the voltage level of 33kV imports energy and terminate within the network area.

Let, P_{N4} be the total energy billed on feeders that import energy and terminate within the network area, $P_m(m = 1,2,3,4,....n)$ is the energy billed on feeders importing energy and terminating within the network area for metered consumers, while $P_u(u = 1,2,3,4,....n)$ is the energy billed on feeders importing energy and terminating within the network area for unmetered consumers.

Then,

$$P_{N4} = \sum_{m=1}^{n} P_m + \sum_{u=1}^{n} P_u \quad (11)$$

A. *Net Sales in Life Camp Area Office Network*

Net energy sales of the network area is given by

$$\phi = \sum_{i=1}^{n=4} P_{Ni} \quad (12)$$

where, $P_{Ni}(i = 1,2,3,4)$ represents total energy billed on all feeders.

B. *Computation of Billing Efficiency*

Billing efficiency is the ratio of Net energy sales of the network area in kWh to the Net input energy of the network in kWh.

Therefore, from equations (4) and (12);

$$\text{Billing efficiency, } \beta = \frac{\sum_{i=1}^{n} P_{Ni}}{\sum_{i=1}^{n} M_i - \sum_{j=1}^{n} N_j} = \frac{\phi}{\gamma} \quad (13)$$

where,

ϕ = Net energy sales of the network area.

γ = net input energy of the network area.

E. Revenue Collection

Analyses of energy billed and amount collected in monetary term according to feeders in the network are presented as follow:

1) *Amount Billed and Collected on Feeders Originating from and Terminating within the Network Area*

Let,

$P_i(i = 1,2,3,4,....n)$ = Amount billed on feeders originating from and terminating within the network area

$Q_i(i = 1,2,3,4,....n)$ = Amount collected on feeders originating from and terminating within the network area

N_{A1} = Total amount of money billed on feeders originating from and terminating within the network area

N_{R1} = Total amount of money collected on feeders originating from and terminating within the network area

Hence,

$$N_{A1} = \sum_{i=1}^{n} P_i \tag{14}$$

$$N_{R1} = \sum_{i=1}^{n} Q_i \tag{15}$$

2) *Amount Billed and Collected on Feeders Importing and Exporting Energy from the Network Area*

Considering the network under study and referring to Figure 1, the feeder with this attribute is Life Camp Feeder. The total amount billed and collected on this feeder comprises the amount billed and collected on 2.5 feeder, 7.5 feeder and Life Camp feeder itself (within and outside the network area). Since the focus is on revenue collection on this feeder within the network under study, certain computation needs to be done as expressed in the following equations.

Total amount billed on feeder importing and exporting energy from the network area (in this case, Life Camp feeder):

$$N_{TL} = h'_{F2.5} + i'_{F7.5} + k'_{LO} + N_{A2}. \tag{16}$$

Also, total amount collected on feeder importing and exporting energy from the network area (in this case, Life Camp feeder):

$$N_{RT} = h''_{F2.5} + i''_{F7.5} + k''_{LO} + N_{R2} \tag{17}$$

where,

$h'_{F2.5}$ = Amount billed on 2.5 feeder

$h''_{F2.5}$ = Amount collected on 2.5 feeder

$i'_{F7.5}$ = Amount billed on 7.5 feeder

$i''_{F7.5}$ = Amount collected on 7.5 feeder

k'_{LO} = Amount billed outside the network area on Life Camp feeder at its voltage level of 33kV.

k''_{LO} = Amount collected outside the network area on Life Camp feeder at its voltage level of 33kV.

N_{A2} = Amount billed within the network area on Life Camp feeder (feeder importing and exporting energy)

N_{R2} = Amount collected within the network area on Life Camp feeder (feeder importing and exporting energy).

3) Revenue Collection on Feeders Originating from the Network Area but Exporting Energy

If,

N_{A3} = Amount billed within the network area on feeders originating from the network area but exporting energy,

N_{R3} = Amount collected within the network area on feeders originating from the network area but exporting energy,

k'_i = Amount of money billed on feeders originating from the network area but exporting energy,

k''_i = Amount of money collected on feeders originating from the network area but exporting energy,

m'_i = Amount billed outside the network area on feeders originating from the network area but exporting energy, and

m''_i = Amount collected outside the network area on feeders originating from the network area but exporting energy,

then,

$$N_{A3} = \sum_{i=1}^{n}\left(k'_i - m'_i\right) \tag{18}$$

$$N_{R3} = \sum_{j=1}^{n}\left(k''_j - m''_j\right) \tag{19}$$

NOTE: Considering the network under study, the only feeder with this attribute is 11kV Dei-Dei feeder.

4) Amount Billed and Collected on Feeders that import Energy and Terminate within the Network Area

Let,

$A_i\left(i = 1,2,3,4,\ldots.n\right)$ = amount billed on feeders importing energy and terminating within the network area.

$B_j\left(j = 1,2,3,4,\ldots.n\right)$ = amount collected on feeders importing energy and terminating within the network area.

N_{A4} = Total amount billed on feeders that import energy and terminate within the network area.

N_{R4} = Total amount collected on feeders that import energy and terminate within the network area.

Hence,

$$N_{A4} = \sum_{i=1}^{n} A_i \tag{20}$$

$$N_{R4} = \sum_{j=1}^{n} B_j \tag{21}$$

Here too, certain workout needs to be carried out on L33 feeder. The focus is on revenue collection on the part of L33 feeder that supplies energy and terminates within the network area only. The total revenue collection on L33 feeder comprises revenue collection on the feeder itself, Jiwa feeder, Gwagwa feeder, and 11kV Dei-Dei feeder (both within and outside the network area).

Total amount billed on L33 feeder:

$$\mathrm{N}_{\mathrm{AL33}} = h_J^{'} + i_G^{'} + k_D^{'} + N_{A33}, \tag{22}$$

Total amount collected on L33 feeder:

$$\mathrm{N}_{\mathrm{RL33}} = h_J^{''} + i_G^{''} + k_D^{''} + N_{R33} \tag{23}$$

Re-arranging equations (22) and (23) to get the amount billed and amount collected within the network area on L33 feeder respectively;

$N_{A33} = \mathrm{N}_{\mathrm{AL33}} - h_J^{'} - i_G^{'} - k_D^{'}$, and

$\mathrm{N}_{\mathrm{R33}} = N_{RL33} - h_J^{''} - i_G^{''} - k_D^{''}$

where,

$\mathrm{N}_{\mathrm{AL33}}$ = Total amount billed on L33 feeder
$\mathrm{N}_{\mathrm{RL33}}$ = Total amount collected on L33 feeder
$\mathrm{N}_{\mathrm{A33}}$ = Amount billed on L33 feeder within the network Area
$\mathrm{N}_{\mathrm{R33}}$ = Amount collected on L33 feeder within the network Area

$h_J^{'}$ = Amount billed on Jiwa feeder

$h_J^{''}$ = Amount collected on Jiwa feeder

$i_G^{'}$ = Amount billed on Gwagwa feeder

$i_G^{''}$ = Amount collected on Gwagwa feeder

$k_D^{'}$ = Amount billed on 11kV Dei-Dei feeder

$k_D^{''}$ = Amount collected on 11kV Dei-Dei feeder

E. Net Revenue Collection in Network Area

This is computed using equations (24) and (25)

Net amount billed on feeders in the network area is given by $\tau = \sum_{i=1}^{n} N_{Ai}$ (24)

Net amount collected on feeders in the network area $\mu = \sum_{i=1}^{n} N_{Ri}$ (25)

F. Computation of Collection Efficiency

Collection efficiency is the ratio of Net amount collected on feeders in the network area to Net amount billed on feeders in the network area as shown in equation (26).

From equations (24) and (25), collection efficiency can be deduced, thus

$$\text{Collection efficiency } \omega = \frac{\sum_{i=1}^{n} N_{Ri}}{\sum_{i=1}^{n} N_{Ai}} = \frac{\mu}{\tau} \tag{26}$$

where,

τ = Net amount billed on feeders in the network area

μ = Net amount collected on feeders in the network area

G. Computation of ATC and C Losses

From equations (13) and (26), the ATC and C Losses in percentage, δ of the Network Area is

$$\{1-(\beta\times\omega)\}\times 100\,\% = \left\{1-\left(\frac{\sum_{i=1}^{n} P_{Ni}}{\sum_{i=1}^{n} M_i - \sum_{j=1}^{n} N_j} \times \frac{\sum_{i=1}^{n} N_{Ri}}{\sum_{i=1}^{n} N_{Ai}}\right)\right\}\times 100\% \tag{27}$$

where,

β = Billing Efficiency

ω = Collection Efficiency

5. Conclusion

This paper presents a methodology for evaluation of ATC & C losses in a typical Nigerian radial distribution system. This was achieved through comprehensive field survey and critical study of the schematic diagram of the network area. The case chosen for this study is unique, having consisted of all the configurations of feeders that could be found in a typical radial distribution system. This has therefore, positioned this work as a handbook to fieldworkers and power utilities when evaluating ATC & C Losses of a radial distribution system.

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