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Aggregated Technical Commercial and Collection Loss Mitigation Through a Smart Metering Application Strategy

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The privatization exercise that led to the creation of 11 distribution companies (Discos) is yet to yield the result of meeting the electricity supply needs of Nigeria. It is in realization of this fact that the Federal Government of Nigeria recently made different proposals and regulations to increase efficiency, availability, and competitiveness within the power industry. This article establishes a technical gain ratio to measure the impact of scaling up smart metering on the aggregated technical commercial and collection (ATC&C) losses. The ATC&C loss is the difference between the amount of electricity received by a distribution company from the transmission company and the amount of electricity for which it invoices its customers plus the adjusted collections loss. To achieve this objective, reviews of historical data of the Discos ATC&C losses and customers' metering records as published by the Nigerian Electricity Regulatory Commission (NERC) for 2015, 2016, 2017, 2018, and 2020 were carried out. In addition, efforts were made to mathematically model the relationship between % metering and % ATC&C losses as this was the framework to help carry out effective forecasts and analyses of the study in order to show the impact level of the strategy employed. One of the salient technical contributions of this article was that it established that for every 1% increase in metering installation, there is a proportionate 0.8% decrease in ATC&C losses, provided all other factors responsible for technical and commercial losses remain constant. Consequently, improved ATC&C loss reduction would be achieved if Discos adopt a combination of other strategies that would ensure reduction in technical and commercial losses in addition to aggressive deployment of meter assets. However, in practice, factors causing technical and commercial losses are never constant as system components depreciate/burn out with time, energy theft, and pilferage, and meter tamper/bypass is on the increase daily; meter deployment is not aggressive enough to match utility customers' growth. Hence, the adoption of combined modern strategies in addition to aggressive metering in tandem with customers' growth has to be employed by Discos in a deliberate attempt to reduce ATC&C losses.

Keywords: distribution companies, aggregated technical, commercial, and collection losses, meter asset provider, Nigerian Electricity Regulatory Commission

INTRODUCTION

The privatization of the power industry by the Federal Government of Nigeria was a thoughtful attempt to improve electricity supply, quality, and reliability across the country (Odje et al., 2018). This exercise resulted in the creation of 6 privately owned generation companies (Gencos), 11 privately owned distribution companies (Discos), and 1 government-owned transmission company (TCN). The government and its citizens were optimistic that the privatization exercise would help solve the erratic electricity supply (Adebayo, 2017). Unfortunately, the unbundling exercise undoubtedly had some gains but also came with its own huge challenges as it exposed the weakened power infrastructure, generation limitations, transmission, and distribution constraints that have deprived the power sector from tangible progress, in spite of the huge government appropriation over the years. More so, the failure of some Discos to attract the needed capital investment required for the dramatic turnaround of their licensed network coverage area leaves citizens wondering if reverting to the preprivatization structure would better serve the energy needs of consumers (Nigerian Senate Report (2, 2020).

In a bid to fast track the closure of the metering gap and encourage the development of independent and competitive meter services in the Nigerian electricity industry, the Nigerian Electricity Regulatory Commission (NERC) issued regulations called Meter Assets Provider (MAP), a scheme which allows to separate entities other than Discos to undertake the provision of metering services in order to meet the metering demand across the country (Nigerian Electricity Regu, 2020a). Furthermore, to break the monopoly of Discos and improve the efficiency of supply, the commission has begun a process of approving regulations that would allow for the subfranchising of Discos original licensed coverage areas to eligible independent investors for effective operation and management. This is a deliberate effort to increase the investors' participation in providing financial liquidity that is required to aggressively build the power infrastructure (Nigerian Electricity Regu, 2019a). In line with this, the Nigerian Federal Government Electricity Roadmap proposal lamented on the underperforming state of the distribution systems, quoting the country's per capita consumption of electricity as of 2015 as 0.15 MWh/capita as against those of other African countries like South Africa and neighboring Ghana, which are 4 MWh/capita and 0.3 MWh/capita, respectively, with the formal being the highest within the African continent. These constraints have undermined the integrity of existing capacities, resulting in the underutilization of the overall power supply system value chain [Siemens (2019). Electrici, 2019].

The distribution system, which is visibly the last mile in the electricity supply chain that is close to the load centers, is a critical infrastructure in the delivery of electricity to connected customers of the national power grid. Highlighting the distribution company challenges in the delivery of quality and reliable supply, the electricity roadmap techno-commercial proposal identified ATC&C losses, distribution network optimization, system expansion, reinforcement, and adequate capital investments as the underlying root causes of the seeming underperformances of Discos. This article therefore seeks to horizontally review the impact of aggressive deployment of smart meters on ATC&C losses as a strategy to drive Discos performances, bearing in mind how central this factor was in the selection of preferred bidders during the privatization exercise.

Electric energy meters which provide the interface for direct billing of consumers by the utility companies have undergone several advancements over the years as conventional electromechanical meters are being replaced with smarter electronic meters to improve accuracy in metering and provide key customer information for database creation, outage management, fault management, load management, network planning, etc. (Jeremy, 2016). Discos still face lean revenue realization owing to network losses, energy theft, meter tamper and/or bypass, and failure of the billing system to capture all billable customers and failure of billing officers to realize all billed energy. Use of analog postpaid meters has further compounded the Disco loss profile owing to error in reading energy consumption, delay in generating bills, distributing bills, shortfall in bill payment, energy consumption calculation disputes, etc. On the other hand, a smart meter is an electronic device with two-way communications that can automatically transmit customers' energy consumption data as well as system operation information to the distribution operating center. Smart meters are prepaid meters and a newer kind of meters that can digitally send meter readings/data to the energy provider for more accurate energy bills. The prepayment mechanism is one of the best features of smart meters that allow for prepayment or pay as we go tariff. We pay for the energy before using it. The meter operates based on the amount/energy unit available at meters. The utility supply is fed to the smart energy meter which has a prepaid card embedded. The prepaid card feeds a low/high signal, i.e., open/close signal to the local contactor depending on the balance left in it. The contactor thus controls the supply to the consumer load, disconnecting it when the prepaid card runs out of balance. When the prepaid card is short of sufficient balance, the consumer makes a recharge request to the utility by prepayment. The utility having received the recharge amount recharges the prepaid card. The utility also receives information about the balance details from the card for the record purposes. Once the unit is exhausted, the meter interrupts/disconnects energy supply automatically. Supply is restored after successful recharging. Smart meters are equipped with antitamper features to detect tampering like missing potential, current transformer (CT), polarity reversal, and phase sequence reversal. Smart meter features include real time-and-date recording, load survey data, import/export data, and tele-metering-remote capacity, among others (Jain and Bagree, 2011; Jiang et al., 2016).

LITERATURE REVIEW

Distribution systems in Nigeria are faced with unique challenges in postprivatization due to the possible maximum thermal loading and wide-area power trading, with rapid varying load patterns, resulting in increasing congestion and energy losses. Losses represent a considerable amount of operating costs. Accurate estimation of electrical losses is imperative to determine with greater accuracy the operating cost for maintaining supply to consumers and accurate estimation of the system lifetime costs over the expected lifetime of the installation. Losses which occur during the process of supplying electricity to consumers from generation stations are classified into technical and nontechnical (commercial and collection) losses. Technical losses are due to energy dissipated in the conductors and equipment used for transmission, transformation, subtransmission, and distribution of power (Siddharth and Dhananjay, 2014; Nigerian Electricity Regu, 2019b).

Also, technical losses are due the system's inherent material property and resistance it offers to the flow of current. Commercial losses occur when the billing process fails to include all billable energies, while collection losses are due to failure of the utility operator to realize revenue in consonance with the billed energy. Thus, ATC&C loss is the sum total of technical losses, commercial losses, and collection losses (shortage due to inability to collect the total billed amount). ATC&C loss is a key gauge to evaluate the financial healthiness of a power utility (Uhunmwangho and Okedu, 2014). The concept of ATC&C losses was adopted in the Multi-Year Tariff Order (MYTO-2.1) by the NERC during the period leading to the privatization of the power industry in 2013. It was a pivotal criterion for deciding preferred bidders. Distribution loss is the difference between energy injected into the system and the energy for which payment was made. It is the cumulative of the transmission and distribution (T&D) losses and loss due to nonrealization of payable demand (Nwohu et al., 2017).

Ideally, losses in an electric system should be about 3–6%. In developed nations, losses are about 10% and about 20% for developing nations. Research shows that ATC&C losses in Nigeria range between 29.4 and 59.1% (Africa-Middle-EastL, 2019). The French Development Agency (FDA) study of the Nigerian power sector performance revealed that the 11 Discos can reduce their ATC&C losses if they invest about N 216.144 billion ($ 600million) within the next 5 years from 2019 (Power Holding Company of, 2018). Hence, utility operators (Discos) in the country are interested in reducing their system's losses so that they can be more competitive since price valuation in the deregulated market is a function of the system's losses (Manju, 2014).

The reasons why technical losses occur in distribution systems span from inadequate investment for infrastructural improvement and over-lengthiness of distribution lines (HT/LT); the lack of adequate maintenance of equipment, substations, and lines; aging equipment; overloading of existing systems,; insufficient reactive power compensation and allocations; the lack of proper network reconfiguration and reconductoring to optimize the length of feeder lines; load balancing,; automatic network response capacities; and elimination of undersized conductors and cables (Mohsin, 2014). The reasons for commercial and collection losses include energy theft and pilferage, a poor metering efficiency, nonreading and erroneous reading of meters, inefficient billing, underbilling, faulty bill distribution, software errors, prolonged disputes, inadequate revenue collection caused by the nonchalant attitude of billing personnel, insufficient collection avenues, and consumer inability to pay for consumed energy (Nigerian Electricity Regu, 2020b). Thus, the three components that make up ATC&C losses are the technical, commercial, and collection losses. Technical losses vary with the transformation capacity of transformers, the conductor type used, and reactive loads among other factors. The total distribution feeder power loss is modeled as the variance between energy injected into a network and the energy consumed as shown in **Eqs 1–3** (Mahmood, 2014)

$$P_T = \beta + \tau \tag{1}$$

$$\beta = \lambda - \varepsilon + \rho \tag{2}$$

$$\tau = \sigma - \gamma \tag{3}$$

where P_T is the total distribution feeder loss, β is the high tension feeder loss, τ is the low tension feeder loss, λ is the input energy to the high tension feeder, ε is the export energy from the low tension feeder, ρ is the consumer's billed energy, σ is the energy input to the low tension feeder, and γ is the billed energy of low tension consumers, respectively.

Commercial losses refer to the illegal consumption of energy. Meter tampering and bypassing in various forms, use of magnets to slow down electromagnetic meter types, damaging or altering of current and/or potential transformer circuits or ratios, and unauthorized resetting of meters are basically related to commercial losses through metering. The most common and visible form of commercial losses is the theft of energy by direct connection to the low tension lines. Distribution companies carry out billing against consumed energy by customers. Often, the utility company is not able to realize the full amount of revenue billed by it. The ratio of the total amount of revenue collected to the total amount billed is termed as collection efficiency. On the other hand, the ratio of total energy billed to the total energy inputted into the network is referred to as the billing efficiency. Therefore, ATC&C losses can be determined using the following relation (R-APDRP, 2009; Shahi, 2011; Gosh, 2012; Dodo, 2020):

$$ATC\&C\ Lossess = \frac{(Total\ Energy\ Input - Energy\ Realized)}{Total\ Energy\ Input} \times 100 \tag{4}$$

$$\alpha = \{1 - (\Gamma \times \eta)\} \times 100\% \tag{5}$$

$$\Gamma = \frac{\phi}{\omega} \tag{6}$$

$$\eta = \frac{\theta}{\pi} \tag{7}$$

where α represents the ATC&C losses, Γ is the billing efficiency, η is the collection efficiency, ϕ is the net energy billed, ω is the net input energy into the network, θ is the net amount of revenue realized from the customers, and π is the net amount of revenue billed by the utility company.

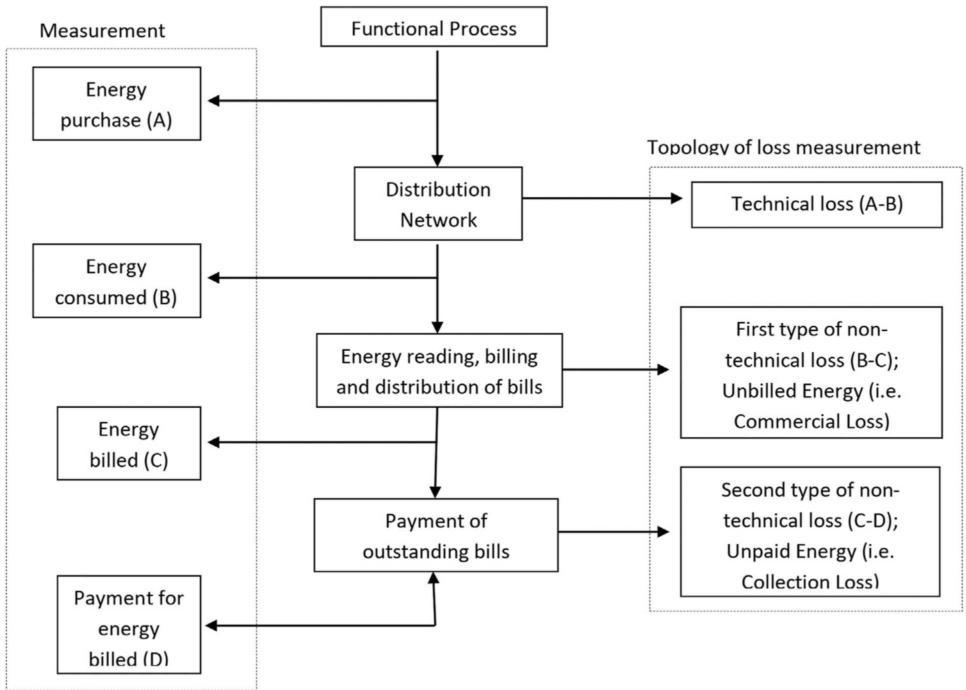


FIGURE 1 | Functional process, measurements, and topology of loss measurements of ATC&C losses (Kirankumar, 2013).

The functional process, measurement, and topology of loss measurements of ATC&C losses are displayed in **Figure 1** using a block diagram (Kirankumar, 2013).

Technical, commercial, and collection loss reduction measures are listed as follows (Ramesh, 2009; Ziari et al., 2010; Ramadoni, 2015; Ines, 2016; Amit and Jitender, 2017; Goran, 2018; Kapoor, 2019):

Technical loss reduction measures are as follows:

- Network reconfiguration and reconductoring.
- Adoption of aerial bunched cables for low voltage distribution lines to replace the all-aluminum conductor (AAC) being currently used.
- Adopt aggressive use of high voltage distribution systems (HVDSs)
- Adoption of widely spread distributed (embedded) power generation within the distribution networks.
- Installation of capacitor banks (shunt or series) for reactive power compensation.
- Install automatic voltage boosters
- Load balancing and load management
- Improve management of distribution transformers
- Regular network maintenance culture
- Increase HT:LT ratio
- Prevent insulator leakages, improve joints and connections, etc.
- Proper geographical information system (GIS), mapping of the network, data collection of the existing infrastructure status, and connected customer enumeration to provide decision making tools for investors to identify asset recapitalization needs
- Integration of modernized solutions

Commercial and collection loss reduction measures are as follows:

- Aggressive deployment and installation of smart prepaid energy meters with tamper and load survey logging features for all categories of consumers
- Sealing of meters with seals and having proper seal management systems
- Installation of CTs/PTs (current transformers/power transformers) in sealed meter boxes so that the terminals are not exposed for tampering and/or bypassing
- Ensure preinstallation testing of meters to confirm the accuracy
- Ensure accuracy in meter reading and billing activities
- Carry out regular energy audit covering the feeders and all end consumers to ensure that there is no revenue leakage beyond the permissible limit
- Strategically choose positions for energy meter installation to expose any illegal activities
- Provide adequate counters and customer collection centers
- Adopt e-bill payment platforms and online services
- Commission adequate collection agents
- Install electronic cash register and drop box facility
- User's association, panchayats, and franchisees in billing and collection.

TABLE 1 | Five year (2015–2018 and 2020) distribution company historic data for % of ATC&C losses (GWh).

Disco	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Ave
Abuja	37	38	63	50	49	43	40	49	33	0	0	0	34
Benin	53	54	66	60	53	48	49	54	61	0	0	0	42
Eko	28	29	55	28	28	23	22	27	40	0	0	0	23
Enugu	52	51	66	51	49	46	43	51	62	0	0	0	39
Ibadan	52	48	70	60	55	49	52	56	64	0	0	0	42
Ikeja	24	20	60	27	21	15	14	22	38	0	0	0	20
Jos	65	66	74	70	60	64	64	70	70	0	0	0	50
Kaduna	57	68	79	81	79	75	72	71	83	0	0	0	55
Kano	43	41	57	60	63	43	46	52	53	0	0	0	38
Port Harcourt	61	62	69	70	60	57	56	51	66	0	0	0	46
Yola	65	74	82	76	73	69	66	70	79	0	0	0	55
Disco	**Jan-18**	**Feb-18**	**Mar-18**	**Apr-18**	**May-18**	**Jun-18**	**Jul-18**	**Aug-18**	**Sep-18**	**Oct-18**	**Nov-18**	**Dec-18**	**Ave**
Abuja	49	46	39	44	48	49	34	37	39	25	33	33	40
Benin	57	59	48	54	52	51	49	52	58	50	56	53	53
Eko	31	25	23	30	31	29	27	30	34	18	28	29	28
Enugu	63	57	51	58	52	58	54	51	58	51	54	53	55
Ibadan	56	51	47	52	49	54	48	52	55	44	48	48	50
Ikeja	41	34	29	39	24	37	28	30	34	23	26	28	31
Jos	76	74	73	79	71	67	61	66	64	53	71	69	69
Kaduna	74	76	63	74	63	69	66	60	75	68	70	75	69
Kano	65	55	53	48	50	54	46	48	59	42	50	49	52
Port Harcourt	72	70	58	67	63	63	62	63	66	60	63	64	64
Yola	70	68	64	75	66	70	64	66	76	62	67	70	68
Disco	**Jan-17**	**Feb-17**	**Mar-17**	**Apr-17**	**May-17**	**Jun-17**	**Jul-17**	**Aug-17**	**Sep-17**	**Oct-17**	**Nov-17**	**Dec-17**	**Ave**
Abuja	53	46	43	52	50	42	49	46	53	44	44	44	47
Benin	58	59	54	52	51	58	49	52	56	57	59	58	55
Eko	37	29	33	40	33	36	35	30	42	29	30	20	33
Enugu	61	57	60	68	55	61	55	58	60	56	56	56	59
Ibadan	56	54	54	58	52	56	55	55	57	47	49	48	53
Ikeja	31	46	36	49	42	43	38	30	35	32	36	30	37
Jos	70	70	70	81	69	76	76	78	72	75	81	74	74
Kaduna	74	77	67	76	72	75	77	70	74	79	76	72	74
Kano	55	60	56	70	57	62	62	62	69	61	58	59	61
Port Harcourt	62	65	62	65	61	67	62	65	69	65	70	68	65
Yola	66	54	56	74	58	69	63	66	71	62	70	65	65
Disco	**Jan-16**	**Feb-16**	**Mar-16**	**Apr-16**	**May-16**	**Jun-16**	**Jul-16**	**Aug-16**	**Sep-16**	**Oct-16**	**Nov-16**	**Dec-16**	**Ave**
Abuja	53	50	59	56	59	53	41	44	45	42	45	48	50
Benin	51	54	62	54	60	58	45	55	59	54	59	52	55
Eko	31	33	30	39	40	34	24	32	36	37	36	34	34
Enugu	58	63	66	65	63	64	56	55	65	64	64	63	62
Ibadan	45	49	52	55	54	48	46	46	54	54	53	49	50
Ikeja	38	44	58	54	38	41	31	29	47	51	57	51	45
Jos	70	76	81	79	77	80	57	72	73	69	68	71	73
Kaduna	73	74	73	76	74	71	66	75	70	75	77	72	73
Kano	57	65	60	65	61	52	29	55	66	66	67	61	59
Port Harcourt	55	57	63	63	65	58	62	56	60	62	58	66	60
Yola	57	66	60	69	70	73	26	53	72	66	64	64	62
Disco	**Jan-15**	**Feb-15**	**Mar-15**	**Apr-15**	**May-15**	**Jun-15**	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Ave**
Abuja	54	53	48	51	58	42	45	48	50	50	54	49	50
Benin	58	64	56	61	64	41	54	56	55	57	54	54	56
Eko	30	39	34	35	37	24	31	39	42	38	36	33	35
Enugu	59	70	62	65	59	54	59	62	64	56	60	61	61
Ibadan	46	58	63	53	49	39	45	50	50	45	48	41	49
Ikeja	45	49	40	46	46	37	34	48	46	42	38	44	43
Jos	59	43	64	66	72	74	67	66	70	73	71	72	66
Kaduna	63	65	64	64	68	56	66	67	73	67	74	63	66
Kano	63	65	52	63	54	42	49	59	56	61	63	60	57
Port Harcourt	52	49	48	59	54	55	58	59	52	44	57	58	54
Yola	56	59	56	55	60	48	49	61	64	58	66	68	58

TABLE 2 | Five year (2015–2018 and 2020) distribution company historic data for percentage of metered customers.

Disco	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Ave
Abuja	0	0	0	0	0	0	0	0	0	0	0	0	0
Benin	0	0	0	0	0	0	0	0	0	0	0	0	0
Eko	0	0	0	0	0	0	0	0	0	0	0	0	0
Enugu	0	0	0	0	0	0	0	0	0	0	0	0	0
Ibadan	0	0	0	0	0	0	0	0	0	0	0	0	0
Ikeja	0	0	0	0	0	0	0	0	0	0	0	0	0
Jos	0	0	0	0	0	0	0	0	0	0	0	0	0
Kaduna	0	0	0	0	0	0	0	0	0	0	0	0	0
Kano	0	0	0	0	0	0	0	0	0	0	0	0	0
Port Harcourt	0	0	0	0	0	0	0	0	0	0	0	0	0
Yola	0	0	0	0	0	0	0	0	0	0	0	0	0
Disco	**Jan-18**	**Feb-18**	**Mar-18**	**Apr-18**	**May-18**	**Jun-18**	**Jul-18**	**Aug-18**	**Sep-18**	**Oct-18**	**Nov-18**	**Dec-18**	**Ave**
Abuja	49	50	50	51	48	49	49	49	48	48	48	49	49
Benin	56	55	55	55	54	54	61	61	60	60	60	60	58
Eko	50	48	48	48	48	48	48	48	48	48	48	49	48
Enugu	46	47	48	51	53	31	32	35	36	37	38	39	41
Ibadan	42	41	41	41	41	40	38	37	37	37	36	36	39
Ikeja	49	48	48	48	48	47	47	47	47	47	47	47	48
Jos	30	30	29	30	31	31	31	31	31	31	31	31	31
Kaduna	57	55	55	60	54	54	54	54	27	24	24	24	45
Kano	26	26	26	27	25	27	28	28	28	29	28	27	27
Port Harcourt	50	51	53	54	55	56	56	58	53	60	60	60	56
Yola	21	21	20	20	20	20	20	21	20	20	20	20	20
Disco	**Jan-17**	**Feb-17**	**Mar-17**	**Apr-17**	**May-17**	**Jun-17**	**Jul-17**	**Aug-17**	**Sep-17**	**Oct-17**	**Nov-17**	**Dec-17**	**Ave**
Abuja	42	42	42	42	42	43	44	45	43	43	47	48	44
Benin	60	61	60	60	59	59	58	58	57	57	56	56	58
Eko	54	54	52	52	53	52	52	52	50	50	50	49	52
Enugu	48	47	46	48	47	47	47	47	47	47	47	47	47
Ibadan	41	40	40	40	40	40	40	41	42	42	42	42	41
Ikeja	51	52	52	51	51	50	50	50	50	49	49	49	50
Jos	29	29	28	28	27	27	27	27	27	27	27	30	28
Kaduna	65	59	59	59	59	59	64	66	63	58	58	58	61
Kano	23	23	23	22	23	24	24	25	26	26	26	26	24
Port Harcourt	40	40	41	40	45	45	45	46	49	50	53	53	46
Yola	23	22	22	22	22	22	21	21	21	21	21	21	22
Disco	**Jan-16**	**Feb-16**	**Mar-16**	**Apr-16**	**May-16**	**Jun-16**	**Jul-16**	**Aug-16**	**Sep-16**	**Oct-16**	**Nov-16**	**Dec-16**	**Ave**
Abuja	46	45	45	40	40	41	41	42	43	43	43	43	43
Benin	61	59	73	74	65	57	60	59	59	59	59	60	62
Eko	56	57	56	57	57	56	56	54	53	54	54	54	55
Enugu	51	50	50	50	50	49	48	48	48	48	48	48	49
Ibadan	41	41	41	41	42	42	42	42	43	42	41	41	42
Ikeja	48	48	48	48	42	42	34	26	40	40	40	37	41
Jos	32	30	29	30	30	30	29	29	29	29	29	29	30
Kaduna	53	49	50	49	48	49	49	49	49	51	61	65	52
Kano	21	23	24	23	24	23	24	23	21	23	23	23	23
Port Harcourt	48	51	50	52	37	42	41	42	38	38	37	40	43
Yola	22	21	22	21	22	22	22	22	22	22	22	21	22
Disco	**Jan-15**	**Feb-15**	**Mar-15**	**Apr-15**	**May-15**	**Jun-15**	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Ave**
Abuja	48	47	49	50	50	51	46	47	47	45	45	45	48
Benin	69	69	70	71	71	71	73	64	62	62	60	64	67
Eko	54	53	53	53	56	57	57	57	57	56	57	57	56
Enugu	54	54	53	54	54	54	54	53	53	52	52	51	53
Ibadan	32	32	32	33	33	33	33	33	33	33	34	34	33
Ikeja	34	34	35	54	53	52	52	51	50	49	48	48	47
Jos	36	26	38	39	40	37	36	34	34	32	32	32	35
Kaduna	38	31	41	42	43	53	51	53	51	54	56	52	47
Kano	37	34	28	28	27	27	28	29	28	32	36	36	31
Port Harcourt	45	44	45	44	42	42	46	50	48	47	48	48	46
Yola	21	16	25	23	14	22	19	2	1	18	13	18	16

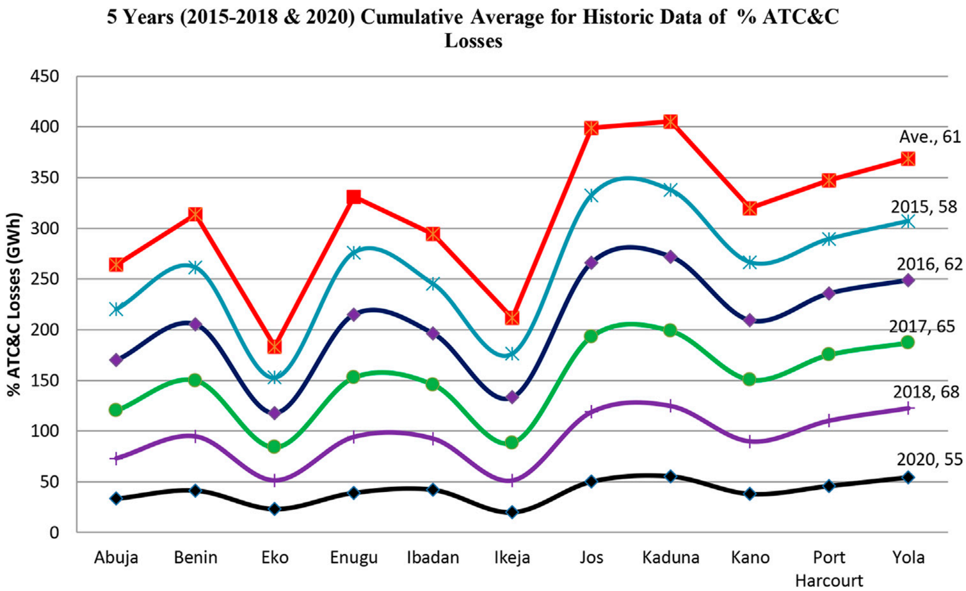


FIGURE 2 | Five year (2015–2018 and 2020) cumulative average for historic data of % ATC&C losses (GWh).

Ideally, optimizing the distribution networks to adopt high voltage distribution systems (HVDSs), aerial bunched conductor distribution lines, and smart prepaid energy meters' installations would drastically reduce ATC&C losses to more than half the conventional low tension system with bare aluminum conductors.

DATA COLLECTION AND PRESENTATION

This article considered a secondary source of historic data published on the NERC website for 5 years (2015–2018, and 2020). This is with regard to the 11 distribution companies' performances based on recorded percentage of aggregated technical, commercial, and collection losses and percentage of metered consumers for 2015 to 2018 and then 2020 (Nigerian Electricity Regu, 2019b; Nigerian Electricity Regu, 2020b). Note that historic data for 2019 were not published on the website by NERC; thus, the obvious omission and year 2020 historic data for % metered customers are zero owing to the impact of corona virus (COVID-19) pandemic lockdown measures. The published data from NERC do not provide numerical values of the numbers of smart meters installed over the period within the catchment areas of each Discos.

In order to demonstrate the impact smart metering scale-up has on ATC&C, we shall perform quantitative analysis of historical data to enable us make futuristic projections. The following are assumptions made:

- All the factors responsible for technical losses remain constant year over year. Hence, the change in technical losses from a year to the next becomes zero.
- All the factors responsible for commercial losses remain constant year over year. Hence, the change in commercial losses from a year to the next becomes zero.
- Discos adopt aggressive smart metering each year, and meters are equipped such that no tampering and meter bypass can occur; also, all billable customers have prepaid smart meters; thereby, 100% billed energy is realized yearly.

TABLE 3 | Five year (2015–2018 and 2020) cumulative average for historic data of % ATC&C losses (GWh).

Disco\ year	2020	2018	2017	2016	2015	Ave
Abuja	34	40	47	50	50	44
Benin	42	53	55	55	56	52
Eko	23	28	33	34	35	31
Enugu	39	55	59	62	61	55
Ibadan	42	50	53	50	49	49
Ikeja	20	31	37	45	43	35
Jos	50	69	74	73	66	66
Kaduna	55	69	74	73	66	68
Kano	38	52	61	59	57	53
Port Harcourt	46	64	65	60	54	58
Yola	55	68	65	62	58	61

Applying these assumptions to account for losses year over year, it implies that the only factors accounting for changes on losses shall be only the level of penetration of smart metering. Therefore, **Eq. 4** literally becomes

$$\Delta ATC\&C\ losses = \Delta Collection\ losses = \Delta\left\{\frac{(Total\ Energy\ Input - Energy\ Realized)}{Total\ Energy\ Input}\times 100\right\} \quad (8)$$

where Δ is the change on an year over year basis for the entity.

TABLE 4 | Projection of Discos scaling-up customer metering by 25% in 2019 over 2018 historic data.

Disco	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Ave
Abuja	61	63	63	64	60	61	61	61	60	60	60	61	61
Benin	70	69	69	69	68	68	76	76	75	75	75	75	72
Eko	63	60	60	60	60	60	60	60	60	60	60	61	60
Enugu	58	59	60	64	66	39	40	44	45	46	48	49	51
Ibadan	53	51	51	51	51	50	48	46	46	46	45	45	49
Ikeja	61	60	60	60	60	59	59	59	59	59	59	59	59
Jos	38	38	36	38	39	39	39	39	39	39	39	39	38
Kaduna	71	69	69	75	68	68	68	68	34	30	30	30	56
Kano	33	33	33	34	31	34	35	35	35	36	35	34	34
Port Harcourt	63	64	66	68	69	70	70	73	66	75	75	75	69
Yola	26	26	25	25	25	25	25	26	25	25	25	25	25

TABLE 5 | Projection of Discos scaling-up customer metering by 25% in 2020 over 2019 historic data.

Disco	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Ave
Abuja	77	78	78	80	75	77	77	77	75	75	75	77	77
Benin	88	86	86	86	84	84	95	95	94	94	94	94	90
Eko	78	75	75	75	75	75	75	75	75	75	75	77	75
Enugu	72	73	75	80	83	48	50	55	56	58	59	61	64
Ibadan	66	64	64	64	64	63	59	58	58	58	56	56	61
Ikeja	77	75	75	75	75	73	73	73	73	73	73	73	74
Jos	47	47	45	47	48	48	48	48	48	48	48	48	48
Kaduna	89	86	86	94	84	84	84	84	42	38	38	38	71
Kano	41	41	41	42	39	42	44	44	44	45	44	42	42
Port Harcourt	78	80	83	84	86	88	88	91	83	94	94	94	87
Yola	33	33	31	31	31	31	31	33	31	31	31	31	32

TABLE 6 | 2019 projection of Discos % ATC&C owing to 25% metering scale-up (GWh).

Disco	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Ave
Abuja	39	37	31	35	38	39	27	30	31	20	26	26	32
Benin	46	47	38	43	42	41	39	42	46	40	45	42	43
Eko	25	20	18	24	25	23	22	24	27	14	22	23	22
Enugu	50	46	41	46	42	46	43	41	46	41	43	42	44
Ibadan	45	41	38	42	39	43	38	42	44	35	38	38	40
Ikeja	33	27	23	31	19	30	22	24	27	18	21	22	25
Jos	61	59	58	63	57	54	49	53	51	42	57	55	55
Kaduna	59	61	50	59	50	55	53	48	60	54	56	60	56
Kano	52	44	42	38	40	43	37	38	47	34	40	39	41
Port Harcourt	58	56	46	54	50	50	50	50	53	48	50	51	51
Yola	56	54	51	60	53	56	51	53	61	50	54	56	55

Thus, from **Eq. 8**, it can be deduced that the change in ATC&C losses year over year varies directly with change in collection losses and inversely with the change in smart metering year over year.

Based on the above, we can simplify **Eq. 8** as follows:

$$\Delta ATC\&C\, losses_{year2} = \frac{\left(\Delta ATC\&C\, losses_{year1} \times \Delta Metering\ deployment_{year2}\right)}{\Delta Metering\ deployment_{year1}} \tag{9}$$

Table 1 displays the 5 year historic records of ATC&C losses across the 11 Discos, while **Table 2** provides information of percentage of installed prepaid meters in each of the Disco's franchised network within the same period.

The historic data presented in **Tables 1**, **2** revealed the high level of ATC&C losses by the 11 Discos as summarized in **Figure 2** and **Table 3**. Kaduna, Jos, and Yola recorded the highest 5 year cumulative average of ATC&C losses of 68% GWh, 66% GWh, and 61% GWh, respectively, while Eko has the lowest 5 year cumulative average of ATC&C losses of 31% GWh, then Ikeja with 35% GWh, and Abuja with 44% GWh. The data show clearly that only Ikeja Disco in 2020 was able to attain the internationally accepted 20% threshold value for ATC&C losses for developing countries. However, within the 5 year

TABLE 7 | 2020 projection of Discos % ATC&C owing to 25% metering scale-up (GWh).

Disco	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Ave
Abuja	31	29	25	28	31	31	22	24	25	16	21	21	25
Benin	36	38	31	35	33	33	31	33	37	32	36	34	34
Eko	20	16	15	19	20	19	17	19	22	12	18	19	18
Enugu	40	36	33	37	33	37	35	33	37	33	35	34	35
Ibadan	36	33	30	33	31	35	31	33	35	28	31	31	32
Ikeja	26	22	19	25	15	24	18	19	22	15	17	18	20
Jos	49	47	47	51	45	43	39	42	41	34	45	44	44
Kaduna	47	49	40	47	40	44	42	38	48	44	45	48	44
Kano	42	35	34	31	32	35	29	31	38	27	32	31	33
Port Harcourt	46	45	37	43	40	40	40	40	42	38	40	41	41
Yola	45	44	41	48	42	45	41	42	49	40	43	45	44

TABLE 8 | Summary of 2019–2020 projection of % ATC&C losses due to 25% metering scale-up (GWh).

Year\ disco	Abuja	Benin	Eko	Enugu	Ibadan	Ikeja	Jos	Kaduna	Kano	Port-harcourt	Yola
2019	32	43	22	44	40	25	55	56	41	51	55
2020	25	34	18	35	32	20	44	44	33	41	44
Average	29	38	20	40	36	22	49	50	37	46	49

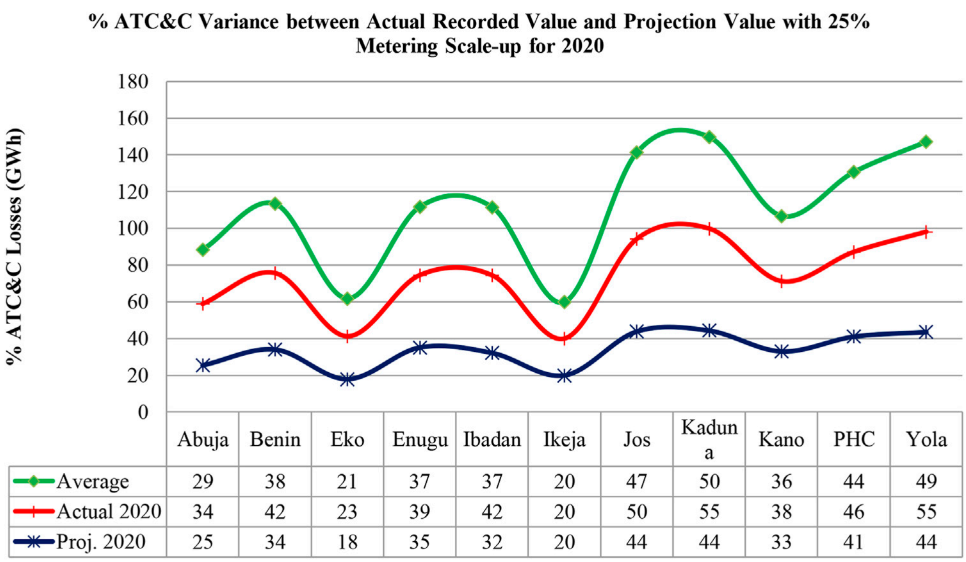


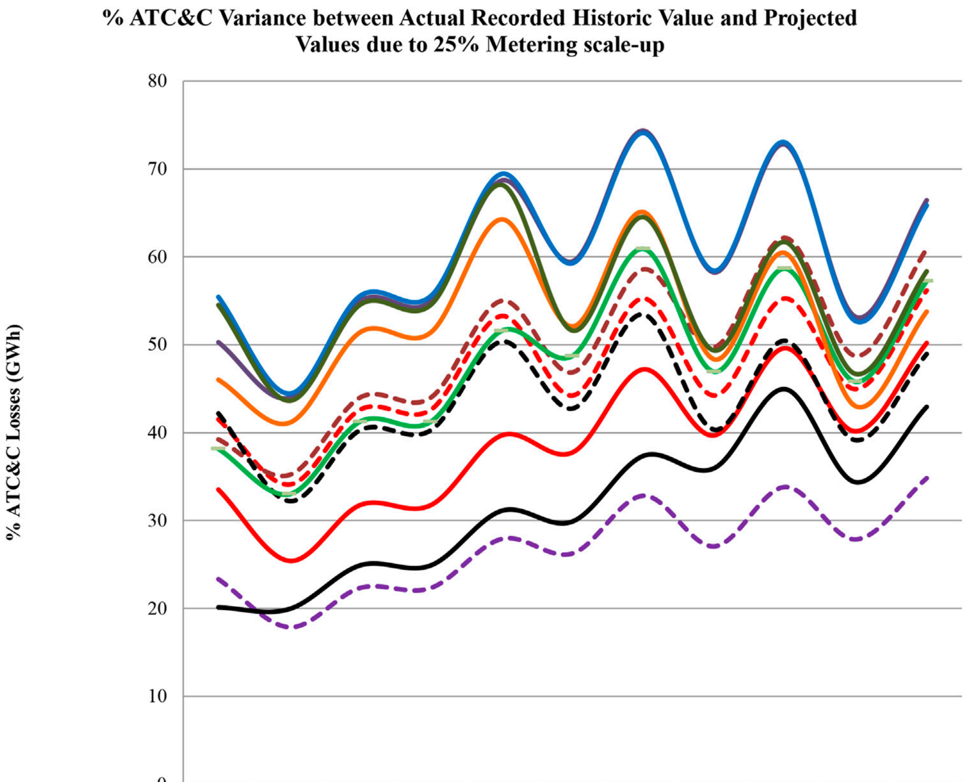
FIGURE 3 | % ATC&C variance between the actual recorded value and projected value with 25% metering scale-up for 2020.

period, none of the Discos were able to achieve the 20% ATC&C loss threshold.

PRESENTATION OF RESULTS AND ANALYSIS

In order to quantitatively analyze the effect of scaling up smart metering on ATC&C losses, we assumed that all the Discos in 2019 and 2020 implemented the strategy that would strengthen their systems to address all factors responsible for collection losses only (other factors remaining constant as per assumption) and ensure the scaling-up of smart energy meters deployment by MAPs that would result in a 25% increase in the number of customers being metered on a year over year basis. The probable effect of Discos adopting this strategy of a 25% increase in the number of metered customers' strategy on ATC&C losses is shown in **Tables 4**, **5** for the years of 2019 and 2020, respectively.

Consequently, the projection for the percentage of ATC&C losses for 2019 and 2020 as a result of a 25% increase in the



	2020 Actual	2020 Proj.	2019 Actual	2019 Proj.	2018 Actual	2018 Proj.	2017 Actual	2017 Proj.	2016 Actual	2016 Proj.	2015 Actual
Abuja	34	25	32	32	40	38	47	40	50	40	50
Benin	42	34	43	43	53	44	55	44	55	45	56
Eko	23	18	22	22	28	26	33	27	34	28	35
Enugu	39	35	44	44	55	47	59	50	62	49	61
Ibadan	42	32	40	40	50	43	53	40	50	39	49
Ikeja	20	20	25	25	31	30	37	36	45	34	43
Jos	50	44	55	55	69	59	74	58	73	53	66
Kaduna	55	44	56	56	69	59	74	58	73	53	66
Kano	38	33	41	41	52	49	61	47	59	46	57
Port Harcourt	46	41	51	51	64	52	65	48	60	43	54
Yola	55	44	55	55	68	52	65	49	62	47	58

FIGURE 4 | % ATC&C variance between the actual recorded historic value and projected values due to 25% metering scale-up.

percentage metered customers is generated by the application of **Eq. 9** on historic data of **Tables 1**, **2** as presented in **Tables 6–8**, respectively.

Performing apple-to-apple analysis, we will realize that the 25% metering scale-up resulted in a 20% reduction of ATC&C losses. Note that the Eko Disco 2019–2020 average % ATC&C value fell to 20% internationally acceptable threshold, whereas Ikeja and Abuja are some few values from attaining the threshold value. Also, it is remarkable to highlight the drop in average annual percentage of ATC&C losses consequently to 25% scale-up of customer metering. This implies that every 1% scale-up of metered customers yielded 0.8% ATC&C loss reduction. **Figure 3** gives the graphical variance for 2020 between actual recorded values and projected values of % ATC&C losses, while **Figure 4** shows the comparison between the actual recorded historic data for % ATC&C losses and the projected value for % ATC&C losses due to 25% metering scale-up from 2015 to 2020, assuming 2015 historic data as reference points.

CONCLUSION AND RECOMMENDATIONS

This article was able to establish a direct gain ratio of smart metering scale-up of ATC&C losses as the presented results show that for every 1% increase of metered customers, there will be a 0.8% corresponding reduction in ATC&C losses. This unique finding will provide a direct gauge and guide for distribution companies' (Discos') planning, budgeting, and strategic policy framing for loss reduction as the gain ratio will further encourage meter asset deployment in the country aimed at improving Discos' viability. Ultimately, implementing this strategy will translate to a better operation efficiency and cost savings for Discos operators and lower tariff for customers. Much more reduction in % ATC&C losses can be achieved if Discos would implement measures that compensate for network inadequacies that are responsible for technical losses and other factors causing commercial losses in addition to aggressive smart metering deployment and installation. These are demonstrated by the convergence in the year 2020 between historic data and projection due to 25% metering scale-up for Ikeja Disco. Although the historic data for 2020 metering were zero owing to the global impact of the COVID-19 pandemic for Ikeja Disco, the convergence of recorded 20% ATC&C losses implies that Disco might have implemented other measures of ATC&C loss reduction that compensated for network inadequacies, which are responsible for technical losses and other factors causing commercial losses.

In order to perform quantitative analysis of the historic data, we assumed that all the factors responsible for technical losses remain constant year over year. Hence, the change in technical losses from a year to the next year becomes zero. All the factors responsible for commercial losses remain constant year over year. Hence, the change in commercial losses from a year to the next year becomes zero. Discos adopt aggressive smart metering each year, and meters are equipped such that no tampering and meter bypass can occur; also, all billable customers have prepaid smart meters; thereby, 100% billed energy is realized yearly. However, in practice, factors causing technical and commercial losses are never constant as system components depreciate/burn out with time, energy theft, and pilferage, and meter tamper/bypass is on the increase daily; meter deployment is not aggressive enough to match utility customers' growth. Hence, adopting a synergy of modern strategies in addition to aggressive metering with customers' growth has to be employed by Discos with drastic intentions to reduce ATC&C losses.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, and further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

MO did the conceptualization, collection, and data analysis of the paper; RU did the literature review and data analysis of the paper; and KO did the data analysis and writing of the paper.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.