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An Improved Electricity Billing Method by Distribution Companies Using Evolutionary Algorithm

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ABSTRACT

The improvement of electricity billing method by the power distribution companies have been a major problem for many years as several attempt have been made to optimize the tatty estimated billing method presently used. This optimization will ensure that everyone is paying the right amount for the electricity they use. Usually bills have been incorrectly estimated, leaving some people paying more and others paying less than they should resulting to heavy financial losses. Since generating and distributing electricity cost money, particularly in a large country like Nigeria, where power lines have to go very long distances and over rough terrain, the current system of estimated billing is very inefficient, which means that as much as one third of the electricity produced leaks away and unpaid for. Hence, the obsolete estimated billing has to stop in order for the improvement of the poor state of electricity infrastructure to be feasible. This will require very huge financial investment. Therefore to achieve this, this dissertation presents an improved electricity billing method by applying python programming using the Port Harcourt Electricity Distribution (PHED) as a case study. The improved method involves the implementation of smart meters to replace estimated bill and simulation run using evolution algorithm. Conclusively, the implemented method and simulation results show optimal solutions, with a substantial difference between estimated bill in which consumers pay less than 50% of actual power consumption and smart metered bill in which consumers are made to pay up 99% of actual power consumption. The calculated losses are shown for the different apartment sizes and total annual loss calculated as ₦1,920,625.

Keywords: Billing method, Distribution companies, Evolution algorithm, Power system, Smart metering,

1.0 INTRODUCTION

Electrical energy is required to ease lifestyle of mankind and stimulate economic growth in reality of both the energy provider and the consumers. Distribution Sector, being the revenue generating link in the Generation - Transmission - Distribution chain is clearly the weakest link in the power sector value chain and is threatening to derail the entire process of power sector reforms. While the power generation sector in the country is struggling to meet rising demand, the Distribution sector has been reeling under losses (Alam *et al*., 2014).

One major problem confronting the electricity industry in Nigeria is in the area of revenue collection from the consumers. This revenue collection or lack of it has been an issue confronting the National Electric Power Authority (NEPA) which is the forerunner of Power Holding Company of Nigeria (PHCN) and other energy distribution companies. The problem is so much that the authority found it challenging to recover the cost incurred to deliver power to consumers in terms of generation, transmission and distribution, equipment procurement and maintenance costs, personnel and other operating cost and thus leaving little or nothing in terms of return on investment to the company.

The aim of this work is to implement an improved electric power billing method called smart metering for the Port Harcourt Electricity Distribution (PHED) Company using evolutionary algorithm to maximize revenue and at the same time offer better reliability of power supply to consumers.

2.0 LITERATURE REVIEW

The passage of Electricity Power Reform Acts (2013) led Nigeria electricity climate through reform process. The act is meant to enhance efficiency in service delivery, promote competition among the players and improve revenue generation from customer billing by these players. However, distribution companies (DISCOs) claim that a fairly large amount of electricity consumers do not pay for electricity used consequently resulting in financial shortfall in the electricity market (Ibiyemi & Tayo, 2018). Fagboun & Femi-Jemilohun (2017) stated that hitherto the Nigeria Power sector was managed by the Federal Government of Nigeria (FGN) as a social service until the choice of privatization in 2013 to be handled by three independent divisions: 1 Transmission Company, 6 Generation Companies and 11 Distribution Companies. FGN takes charge of the Transmission while the other two segments are managed by private investors. Salihu *et al*. (2016) observed that DISCOs generate their income from billing the consumers for energy used. The greatest challenge facing generation and distribution companies is paucity of fund to meet up with associated costs and to cope with high aggregate technical and commercial costs of delivery. Since the handover of distribution to 11 private distribution companies in Nigeria, there have been series of complaints from consumers on poor service delivery (poor or no service in some areas), excessive billing using estimated billing instead of metering, etc. On the other hand, the DISCOs challenge has been with, attitude of some consumers to bills payment, inadequate supply from generation/transmission companies, sabotage by staff and consumers, old equipment, cost of fund and inadequate finance to purchase equipment and materials needed to sustain acceptable customer satisfaction level and good return on investment. Rathnayaka *et al*. (2013) stated that it is important to note that the problems associated with billing for electricity and payment by consumers play key roles affecting the system to grow the income of both the distribution company and the energy users. The progenitor of PHEDC, that is, NEPA/PHCN was using the analogue metering system in the past, to monitor consumers' power usage and charge them based on energy consumed. The billing method thus used involves the physical reading of the meter by field officers. These readings are submitted at the office for computation and billing. Bills are computed based on the prevailing tariffs and they are distributed to the consumers for payment within a set time frame. Bills payments by consumers are made to the company mostly in cash through designated offices. This method of settling bills is observed to have some challenges such as:

a) Cash handling and management
b) Unnecessary exposure of Cashiers to danger
c) Inconvenience of Consumers who sometimes stay long on queue waiting to pay their bills
d) Late delivery of bills and sometimes non delivery at all, thus exposing the consumers to disconnection

But in recent times, and with improvement in the banking system, bill payment can be made through online portals, and direct payment into dedicated accounts through the bank was encouraged. In some instances, the DISCOs are however observed to be reluctant to change from the manual process because of the extra effort, especially the huge cost for new solution that will be required.

Abdulwahab (2009) stated that in times past, and due to limited number of consumers, NEPA employed the use of manually reading the analogue meters and billing customers based on the prevailing cost per unit. Consumers' consumption serves as input for the billing. The analogue meter measures the amount of electric energy supplied to consumers. The most common type of analogue meter is the electro-mechanical induction meter properly known as Kilowatt hour meter. The electro-mechanical induction meter operates by counting the revolutions of a non-magnetic, but electrically conductive, metal disc which is made to rotate at a speed proportional to the power passing through the meter. The number of revolutions is thus proportional to the energy usage. Fagbohun et al. (2017) stated that reasons including uncontrolled urban and rural developments giving rise to connections to the electric distribution networks, DISCOs face the challenge of providing meters to consumers' facilities. However, in order to get some revenue from these unmetered customers, estimated billing is being used. Abdulwahab (2009) stated that the trend of the time has always been in favor of that technology which finally become cost-effective as well as an elegant one. Traditional meter reading is done by the human operator, this require more number of labor operator and long working hour to achieve the complete area data reading and billing. Due to increase in the development of residential buildings and commercial buildings, the task of meter reading increases, which means it requires more number of human operators. In order to achieve efficient meter reading, reduce billing error and operations cost, automatic meter reading system play an important role. Thakur et al. (2002) stated that energy meters installed at the consumer terminals provides the basis for the billing of the energy consumed. Besides this, the meter reading also helps in the computation of energy loss in the distribution network. Customers are expected to pay the bill as metered for energy the used after a given period. Challenges however arise because the payment is billed after usage and the company has no means to recover even when the bills are not settled. This is the post-pay method which has been noted to be no longer realistic as it does not support revenue collection efficiency.

Ofonyelu & Chidi (2014) observed that number of evidences suggest that electricity billing in Nigeria is asymmetric before the introduction of pre-pay meters. The largest occurrence of asymmetry in electricity billing occurs for consumers who were not metered. It occurs because ownership of meter gives room for consumers to monitor their consumption and know the amount of energy actually consumed. Being metered gives the consumer opportunity to be able to calculate own bill, having known the amount of energy consumed. As a result, metering essentially helps to reduce the tendencies for asymmetry. Amadi (2013) observed that the issuance of estimated bills by the electricity distribution companies (discos) gives room to cheating the consumers.

Ogun & Ofonyelu (2013) opined that metering all electricity consumers would assist the customer to effectively monitor their electricity usage, as well as enable the discos determine their revenue thereby driving for its collection. The prepaid metering platform was aimed at addressing the asymmetries from both the sides of the consumers and the utility company. Gupta (2017) proposed that the way out of the challenges to cash flow experienced from estimated and post-paid billing methods is with introduction of pre-pay method. This is a method whereby consumers are made to pay ahead of enjoying service. It also gives the consumers opportunity to pay attention to their energy consumption rates. Prepay meters have the advantage of being able to automatically cutting off supply to consumers at the exhaust and/or expiry of paid electricity energy units without physical disconnection from the grid as is usually the case with post-paid and estimated billing systems. It also eliminates the frequency of unpaid bills and lowers overhead costs because the meter readers are eliminated and their services may be utilized in other assignments. Several works have been carried out on prepay method of electricity billing system. Vijayaraj & Saravanan (2010) noted that with the Global System of Mobile (GSM) telecommunication system, the Central Electric Billing (CEB) Office can have immediate access to all consumer homes in a locality with the help of Radio Frequency system. The EB meter present in each house is connected by wireless network with the EB office which periodically gets updates from the meter. The EB office using a backend database calculates the amount to be paid according to the number of units consumed and sends it back to the meter for display and also to the user's mobile phone. The advantages of the proposed system make the existing system incompetent. It is possible to connect to remote areas even when there is a power failure as it employs wireless technology. Quazi et al. (2007) reported the work done on pre-paid energy meter using automatic voltage regulator (AVR) controller. In this method microcontroller 8051 has been replaced by AVR controller because, it is energy efficient i.e. it consumes less power, it is fastest among all the microcontroller families, it has inbuilt ADC and have advanced RISC architecture. In the paper, it was observed that energy meters which is already installed at our houses will not been replaced, but a small modification on the already installed meters can change the existing meters into prepaid meters, so this meters are cheap. From the early works done on the billing methods, it was clear that for effective collection of bills, the customers must have confidence in the bill to represent the energy consumed. Electronic and/or automated systems thus became the preferred option.

3.0 MATERIALS AND METHOD

This section presents the details of the problem and the solution methods, smart metering Evolution algorithm.

3.1 Smart Meters

A smart meter is an electronic device that records consumption of electric energy and communicates the information to the electricity supplier for monitoring and billing purposes. Smart meters typically record energy hourly or more frequently as may be desired, and send the reading to the central data collation point for necessary computations on timely basis. Smart meters enable two-way communication between the meter and the central system. Smart meters use a secure national communication network to automatically and wirelessly send actual energy usage by consumer to your supplier. This means households with a smart meter would not need to rely on estimated energy bills or bills read from postpaid meter rather an in-home display gives the household real-time usage information including kWh use and cost.

In the implementation of smart metering system, an additional cost of metering communication device and installation/maintenance cost will be added by the company but the cost of energy lost to non-metering and thus collection loss is minimized and thus maximizing recovered revenue N_P.

If the total cost of smart meters that will be installed for customers is represented by:

$$TCS = \sum_{s=1}^{n} \mathrm{Ps} + \sum_{c=1}^{n} \mathrm{Mc} \qquad (1)$$

Where:

TCS = the total cost of smart meter

P_S (s = 1,2,3……..n) = the purchase cost of the smart meters by customers

M_C (c = 1,2,3……n) = the installation and maintenance cost of the smart meters

This cost will be minimized and discounted over long period of service.

3.2 Evolution Algorithm

In order to carry out this task, it was required to have closer look at what is obtainable. Electric bills issued by the PHEDC to consumers will be studied along with the customers' payment response. The mode of bill generation and distribution to consumers' premises was also studied for possible areas of improvement. The evolutionary algorithms working on MATLAB will be used to analyze these different methods of reading and generating electric energy bills in order to arrive at a suitable method of reading the meter and generating of electricity bills.

Evolutionary Algorithms (EAs) are stochastic search and optimization heuristics derived from the classic evolution theory, which are implemented using the following parameters:

Random Generation:

$$x_{ij} = x_{\min j} + rand[0,1]\left(x_{\max j} - x_{\min j}\right) \qquad (2)$$

Fitness Value (FV):

$$x_{ij}^{j} = x_{ij} + \phi_{ij}\left(x_{ij} - x_{kj}\right) \qquad (3)$$

Probabilistic FV solution selection:

$$prob_i = \frac{fitness_i}{\sum_{i=1}^{SN} fitness_i} \qquad (4)$$

Where:

x_{ij} = Position of food source *i* in direction *j*

$x_{\min j}$ = Lower bound of x_i in direction *j*

$x_{\max j}$ = Upper bound of x_i in direction j
SN = Food source number
D = Dimension of the problem
ϕ_{ij} = Random number between -1 and +1
$fitness_i$ = Fitness value of solution i

The purpose of this work is to check performance of the distribution company with respect to the energy received from the grid, its sales and collection from the consumers. It consists of two main terms of energy input and energy sold and the mathematical formulation of the terms used is given below:

1) Total energy input from the grid referred to as E_{in}
2) Total energy sold by company referred to as E_{ex}

These can be represented mathematically as:

Mi (i = 1,2,3…….n) represent measured energy input from the grid network by company and

Nj (j = 1,2,3……n) represents total energy export to consumers by company

Then it can be said that total energy from the grid is:

$$Ein = \sum_{i=1}^{n} \text{Mi} \quad (5)$$

Total energy exported to consumers is

$$Eex = \sum_{j=1}^{n} \text{Nj} \quad (6)$$

Hence the Net Energy loss of the system is given by:

$$\gamma = \text{Ein} - \text{Eex} = \sum_{i=1}^{n} \text{Mi} - \sum_{j=1}^{n} \text{Nj} \quad (7)$$

For optimal performance the net energy losing the system is expected to be 0 (zero)

The net energy has to be sold to consumers at the agreed tariff by company. This sale is expected to be achieved from both metered and unmetered power sold to consumers as follows

$$\sum P = \sum_{x=1}^{n} \text{Px} + \sum_{y=1}^{n} \text{Py} \quad (8)$$

where

Px (x=1, 2, 3…….n) represents metered energy sold

Py (y=1, 2, 3……n) represents unmetered energy sold by company

From information received in the assignment, it was observed that not all the customers are billed as desired for one reason or the other. It was observed that not all the energy received is billed to consumers for some reasons. However, the energy sales can be represented as

$$\sum \text{Pe} = \sum_{h=1}^{n} \text{Ph} + \sum_{i=1}^{n} \text{Pi} \quad (9)$$

Where P_h (x=1, 2, 3…….n) represents billed metered energy

P_i (y=1, 2, 3……n) represents unbilled metered energy

Total energy billed by company can be represented by

$$\alpha = \sum_{i=1}^{n} PNi \quad (10)$$

where:

P_{Ni} (Ni = 1, 2, 3 ….n) is the energy billed by the company.

From the foregoing, the billing efficiency of the company can be obtained by the ratio of energy billed by company to the net energy of the company. Hence from (4) and (6), we have:

$$\text{Billing efficiency } (\beta) = \frac{\sum_{i=1}^{n} PNi}{\sum_{i=1}^{n} \text{Mi} - \sum_{j=1}^{n} \text{Nj}} = \frac{\alpha}{\gamma} \quad (11)$$

On the other hand, it was also noted that it is not all the energy bills issued by company that is being paid by consumers thus resulting in collection losses.

If Pi (i =1, 2, 3,…n) is the amount billed to consumers by company; Qi (i=1, 2, 3, ...n), is the amount of revenue collected from customers by company; N_B is the total value of money billed by company to all the consumers in the network in the subject period and N_P is the total amount of money paid by the consumers, then:

$$N_B = \sum_{i=1}^{n} Pi \quad (12)$$

$$N_P = \sum_{i=1}^{n} Qi \quad (13)$$

The ratio of total amount of money collected from consumers to the bills issued gives the collection efficiency of the company. Thus, the collection efficiency can be calculated as:

$$\text{Collection efficiency, } \eta = \frac{\sum \mathrm{NP}}{\sum \mathrm{NB}} \quad (14)$$

Combining the (4) and (10), the aggregate technical commercial and collection (ATC & C) losses for the company can be obtained in percentage as:

$$\mathrm{ATC\&C} = \{1 - (\beta \times \eta)\} \times 100\% \quad (15)$$

From the above equations, it is imperative that the company must maximize the collection from customers $N_{P.}$

3.3 Materials Used

The data presented in this work was collected from the Port Harcourt Electricity Distribution Company (PHED) and the Nigerian Electricity Regulatory Commission (NERC). The data collected comprise of the following;

- PHED Report showing amount of bills generated and collected for the whole Port Harcourt Township covering Borokiri, Ibeto, Maccoba, Marine Base, Old GRA and Ogbunabali over a period of six months.
- PHED Quarterly report with parameters used to evaluate commercial activities of the DISCO in terms of energy received, energy billed to consumers, energy available from grid and bill performance covering the period of Q3, 2017 up to Q1, 2019.
- PHED Data showing energy received from grid versus the energy demand by PHED over the reference period.
- PHED Aggregate technical, commercial and collection losses.
- NERC report showing energy received and energy billed by DISCOs across Nigeria including Port Harcourt which is the case study in 2018/Q2-Q3.
- NERC Revenue performance report of DISCOs across Nigeria including Port Harcourt in 2018/ Q2-Q3
- NERC aggregate technical, commercial and collection losses (%) for DISCOs across Nigeria including Port Harcourt in 2018/Q2-Q3
- NERC DISCOs quarterly remittances report to BET and Market operators MO across Nigeria including Port Harcourt in 2018/Q2-Q3.

These data which is summarized in the tables below are required for an extensive analysis of the PHED, identifying challenges and deficiencies in the area of revenue generation and cash flow from electricity bills distributed to consumers, thus determining performance and efficiencies.

Optimization of PHED started with the analysis of existing data and method to determine performance, efficiency and limitations and then python is applied on EA to analyze different methods of reading and generating electrical energy bills in order to arrive at an optimally suitable method that minimize the declined performance and losses and at same time maximizing revenue, remittances and collection efficiency as well as carry out simulation.

Table 1 shows the amount of bills generated and the collection for the whole of Port Harcourt town, which include Borokiri, Ibeto, and Maccoba, Bundu, Marine Base, Old GRA and Ogbunabali areas over the period of January to July, 2019.

Table 1: PHED Billing and Payment for Port Harcourt Township (Jan – July, 2019)

S/No	Month	Bill Count	*Bill kWh*	Pay Amount	Response
1	January	15,436	9,260,305	140,794,966.9	10,234
2	February	15,456	9,221,126	166,423,562.1	9,559
3	March	15,567	6,866,894	134,419,351	9,609
4	April	18,918	9,498,017	134,924,409	9,727
5	May	18,918	9,498,017	207,669,780	10,104
6	June	20,676	7,512,423	155,719,316.2	11,430

Table 2 below shows a track of the parameters used to evaluate commercial activities of the DISCO in terms of energy received, energy billed to consumers, energy available from the grid and bills performance covering the period 2017 Q3 up to 2019 Q1.

Table 2: Energy Received from Grid and Billed to Customers

Period	Total Energy Received GWh	Total Energy Billed GWh
2017 Q3	507	387
2017 Q4	586	396
2018 Q1	526	368
2018 Q2	455	359
2018 Q3	455	357
2018 Q4	504	357
2019 Q1	507	378

Table 3 shows that there is high variance from the performance of PHED related to her performance expectation. From the table, the company has not been able to meet up her quarterly or annual target

Table 3: Load Demands versus Grid Load Allocations

Period	Actual Load Demand	MYTO Load Allocation
2017 Q3	8.0	7.7
2017 Q4	8.3	6.5
2018 Q1	7.7	6.5
2018 Q2	7.0	6.5
2018 Q3	7.1	6.5
2018 Q4	7.1	6.5
2019 Q1	7.0	6.5

(Note: These figures are percentage of National Load)

Table 4 shows revenue collection trend contributes greatly to the challenging performance of PHED as the company has been faced with mounting issues to meet up with her expected aggregate technical commercial and collection losses (ATC&C)

Table 4: Revenue Collection

Period	*Total Energy Billed (N Billions)*	*Total Revenue Collected (N Billions)*
2017 Q3	13.9	6.3
2017 Q4	14.2	6.2
2018 Q1	13.3	6.1
2018 Q2	13.0	6.3
2018 Q3	12.8	6.3
2018 Q4	12.9	6.7
2019 Q1	13.6	6.7

Table 5: ATC&C Losses Allowance versus Actual Performance

Period	*MYTO Allowance %*	*Average Quarter Perf %*	*Average Annual Perf %*	*Overall Avg ATC&C Overall Avg ATC Perf Perf %*	*%*	*Overall Avg Collection Perf %*
2017 Q3	37	65	65	54		
2017 Q4	37	68	65	51		
2018 Q1	29.7	66.88	67	55.01		
2018 Q2	29.7	64.21	6	54.24		
2018 Q3	29.7	61.46	67	46.96	18.94	34.34
2018 Q4	29.7	63.08	67	47.92	23.64	31.79
2019 Q1	26	63.26		48.72	19.67	35.96

3.4 Simulation Parameters

Simulation was done with Python programming language, using the following parameters, after initial experiments to tune the parameters:

a) No. of Generations = 300
b) Population Size = 100
c) Crossover probability (Pc) = 1.0
d) Mutation Probability (Pm) = 0.006
e) Light hour per day = 8hours
f) Sizes of sample buildings = 3 Bedroom Flat, 2 Bedroom Flat, 1 Bedroom Flat, Self-contained and Single room apartment
g) Energy charge/kWh = 37.56 naira /kWh
h) Appliance rating:

- Television = 200W
- Home Theater = 250W
- Fridge = 200W
- Lighting = 60W
- Electric Fan = 80W
- Air Conditioner = 1000W
- Water Heater = 1000W
- Miscellaneous = 100W
- Microwave = 1000W
- Pressing Iron = 1000W
- Bread Toaster = 1000W

Table 6 Shows Calculated Load Based on Appliances Connected.

S/No	Apartment Type	Total kWh/day	Total kWh/year
1	One room	9.12	3328. 799
2	Self-contained	17.62	6431.30
3	One bedroom	34.0	12410.00
4	Two bedrooms	50.88	18571.00
5	Three bedrooms	70.0	25550.00

Table 7 Representative samples used for Simulation

Description	One room	Self contain	1Bedroom	2Bedroom	3Bedrom
Television	**1**	**1**	**1**	**1**	**1**
Home Theatre	**1**	**1**	**1**	**1**	**1**
Fridge	**1**	**1**	**1**	**1**	**2**
Bulbs	**3**	**8**	**12**	**16**	**20**
Pressing Iron	**1**	**1**	**1**	**1**	**1**
Fan	**1**	**2**	**2**	**3**	**5**
Toaster	**1**	**1**	**1**	**1**	**1**
Air Conditioner	-	**1**	**2**	**3**	**4**
Water Heater	**1**	**1**	**1**	**2**	**3**
Micro Wave Oven	-	**1**	**1**	**1**	**1**
Miscellaneous	-	-	-	-	-

Table 8 Estimated Time of Appliance Use

S/no	Code	Duration	Description
1	**T1**	**8hrs/day**	**Television, home theatre, fridge, bulbs fan, water heater**
2	**T2**	**1.5hrs/day**	**Pressing iron**
3	**T3**	**1hr/day**	**Air conditioner**
4	**T4**	**0.5hrs/day**	**Toaster, Micro wave**

4.0 RESULTS AND DISCUSSION

4.1 Case Study of PHED Billing Data for Port Harcourt Township

The data used in the analysis represent existing/live PHED billing data for the Port Harcourt Township over a period of six months in 2018.

Table 9 Bill Collection for PHED

S/No	Month	Bill Amount	Bill Count	Bill kWh	Pay Amount	Response
1	Jan	347,812,373.96	15,436	260,305	140,794,966.95	10,234
2	Feb	343,869,168.66	15,456	221,126	166,423,562.11	9,559
3	Mar	259,079,155	15,567	866,894	134,419,351.00	9,609
4	Apr	351,288,344	18,918	498,017	134,924,409.00	9,727
5	May	351,288,344	18,918	498,017	207,669,780.00	10,104

6	Jun	288,008,652.52	20,676	512,423	155,719,316.28	11,430

From Table 9, it is seen that in January, February and April customers paid less than 50% of the energy they consumed and it is observed that less than half of the consumers paid for the energy consumed. In some cases, part of the bills are settled leaving some and by the time the following month bill is received, another token amount is paid thus increasing the net debt to be paid to the company. This attitude of customers is causing the DISCO to have an elevated commercial and collection losses which affects her ATC&C losses performance. It can be seen that for this area of operation, covering the Government facilities such as the State Secretariat, House of Assembly, Teaching Hospital, etc. with fairly stable energy supply to the customers, response in terms of bills settlement has not been commensurate to the effort of PHED. This contributes to the low collection efficiency of the company as shown in Table 9. Concerted efforts are being made to increase the number of customers billing as can be seen with the steady increase in June. Another critical observation was that the DISCO has not been billing the total energy received from the grid to her customers due to some challenges; despite that not all that was billed got paid for by the customers. This results in a high net loss to the company as can be seen in Table 10. The company monthly performance can be seen in the record obtained over a period of two years below.

Table 10: PHED Energy received from Grid and Billed to Customers from Q3 2017 to Q1 2019

Period	Total Energy Received GWh	Total Energy Billed GWh
2017Q3	507	387
2017Q4	586	396
2018Q1	526	368
2018Q2	455	359
2018Q3	455	357
2018Q4	504	357
2019Q1	507	378

From Table 10, with total energy received and total energy billed tabulated above, we can determine the billing efficiency for each month thus:

Billing Efficiency (%)

$$= \frac{Energy\ billed}{Energy\ \text{Received}} \text{ x } 100 \quad (16)$$

Table 11: PHED Billing efficiency for period 2017 Q3 to 2019 Q1

Period	Total Energy Received GWh	Total Energy Billed GWh	Billing Efficiency %
2017 Q3	507	387	76
2017 Q4	586	396	68
2018 Q1	526	368	70
2018 Q2	455	359	79
2018 Q3	455	357	78
2018 Q4	504	357	71
2019 Q1	507	378	75

With the efficiency of billing determined as shown in the table above, it can be seen that the quantity of energy billed is not up to the energy available to consumers. Over the period, the average bills generated is about 74% of the energy received. In practical term, this means that more than a quarter of the energy received by the DISCO is not being accounted for. This huge quantum is being lost to energy theft, lack of energy meters or other sundry reasons. In order to get some income from the unmetered customers and thus get some revenue from the energy thefts, the company employs the use of estimated billing method in accordance with the NERC regulation. However, this billing method is having issues including being unacceptable by customers thus leading to wrong attitude of not paying the due bills. Impact of this is that the utility company will not be able to meet up her responsibility to the GENCO and thus the energy available for the grid is being challenged for obvious reasons.

Table 12: PHED Revenue Collection from 3rd Quarter 2017 to 1st Quarter 2019

Period	Total Energy Billed (NBillions)	Total Revenue Collected (NBillions)
2017Q3	13.9	6.3
2017Q4	14.2	6.2
2018Q1	13.3	6.1
2018Q2	13.0	6.3
2018Q3	12.8	6.3
2018Q4	12.9	6.7
2019Q1	13.6	6.7

Using the formula for Collection efficiency, $\eta = \frac{\sum NP}{\sum NB}$ (17)

Where:

N_P (₦ Billions) is the Total revenue collected in Naira Billions

N_B (₦Billions) is the Total energy billed in Naira Billions

The revenue collection efficiency can be calculated and values are seen in Table 12.

Table 13: PHED Collection Efficiency for period 2017Q3 to 2019Q1

Period	Total Energy Billed (N Billions)	Total Revenue Collected (N Billions)	Collection Efficiency %
2017 Q3	13.9	6.3	45.2
2017 Q4	14.2	6.2	44.0
2018 Q1	13.3	6.1	45.9
2018 Q2	13.0	6.3	48.7
2018 Q3	12.8	6.3	49.1
2018 Q4	12.9	6.7	51.9
2019 Q1	13.6	6.7	49.2

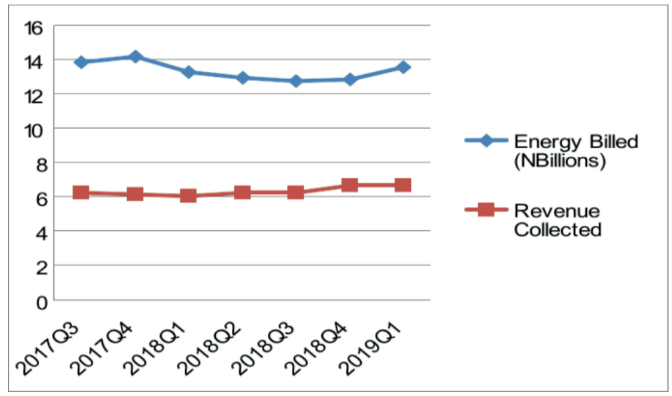

Fig. 1: Comparison of Total Energy Billed against Total Revenue Collect by PHED

The efficiency of revenue collection from bills settlement over the period shows an average of less than fifty percent (50%). It shows that a large number of electricity energy users are consumers and not customers. In this context, a customer is defined as one that have a commercial relationship with the utility within the applicable regulatory framework i.e. they pay the full price of the energy they consume while consumers on the other hand are electricity users who consume electricity in one way or the other either through theft, partial or nonpayment for their energy consumption (Adesua, 2018). In other word, this category of consumers include meter bypass, no meter, direct and illegal connections and those with meter but not willing to pay for reasons best known to them.

The high number of these consumers as can be seen from Table 12 which means that about half of the energy billed are not settled or remains unpaid. It is indeed a big problem that is being experienced over a long period of time. Hence PHED needs to have a closer look at, and proffer solutions to close the identified gaps. The above factors contributes greatly to the challenging performance of PHED as the company has been faced with mounting issues to meet up with her expected aggregate technical commercial and collection losses (ATC&C). The performance over the period is shown in Table 13.

Table 14: PHED Performance in ATC&C for period 2017Q3 to 2019Q1

Period	MYTO Allowance (%)	Average Quarter Performance (%)
2017 Q3	37	65
2017 Q4	37	68
2018 Q1	29.7	66.88
2018 Q2	29.7	64.21
2018 Q3	29.7	61.46
2018 Q4	29.7	63.08
2019 Q1	26	63.26

It needs to be recall that at the point of engagement by the Bureau of Public Enterprises and in conjunction with NERC, yearly target ATC&C was given to the DISCOs as part of the performance targets, aimed at gradually tapering the system's ATC&C loss to about 25% average at the end of the then agreed 5 years' service period. Table 14 however shows that there is high variance from the performance of PHED related to her performance expectation. The performances in terms of energy billing, revenue generation and collection as well as ATC&C for all the DISCOs are shown below for comparison purpose.

Table 15: NERC Grid Energy Received and Energy Billed

DISCOs	Total Energy Received (GWh) 2018/Q3	2018/Q2	Total Energy Billed (GWh) 2018/Q3	2018/Q2	Billing Efficiency (%) 2018/Q3	Billing Efficiency (%) 2018/Q2
Abuja	837	900	671	771	80	86
Benin	625	635	538	546	86	86
Eko	747	801	679	756	91	94
Enugu	539	535	357	376	66	70
Ibadan	840	850	689	728	82	86
Ikeja	856	857	801	853	94	99
Jos	285	288	183	207	64	72
Kaduna	503	511	362	355	72	66
Kano	460	487	375	410	82	84
Port Harcourt	455	455	357	359	78	79
Yola	229	281	148	160	65	73
Totals	6,376	6,537	5,160	5,500	81	84

The performance of the DISCOs in Table 15 for 11 major cities in Nigeria shows that Port Harcourt had one of the lowest billing efficiency of 78% and 79% in the 3rd and 2nd quarter of 2018 respectively coming 8th position of the 11 cities compared to Ikeja which had the highest billing efficiency of 96% and 99% respectively. This report performance proves how poorly performed PHED is and needs immediate intervention.

Table 16: NERC Revenue Performance by DISCO

DISCOs	Total Billings (N Billions) 2018/Q3	2018/Q2	Revenue 2018/Q3	Collected (N Billions) 2018/Q2	Collection Efficiency (%) 2018/Q3	2018/Q2
Abuja	21.9	26.6	17.2	17.1	78.2	66.8
Benin	19.1	19.4	10.6	11.0	55.5	56.8
Eko	20.5	22.5	16.0	17.8	78.0	78.8
Enugu	13.1	14.0	8.8	9.4	66.9	67.1
Ibadan	20.9	21.0	12.4	13.0	59.5	60.0
Ikeja	22.5	22.8	18.8	19.0	83.4	83.3
Jos	6.7	7.4	3.7	3.0	55.7	39.8
Kaduna	10.3	10.5	4.6	5.2	44.6	49.9
Kano	11.4	12.5	6.7	7.7	59.0	62.0
Port Harcourt	12.8	13.0	6.3	6.3	49.1	48.7
Yola	3.9	4.40	1.9	2.0	47.6	45.0
Total	163.2	173.7	107.0	111.5	65.6	64.2
Average	14.8	15.8	9.70	10.1	61.6	59.8

Table 16 shows Port Harcourt collection efficiency was low at 49.1% and 48.7% in 3rd quarter and 2nd quarter as compared to Ikeja which had the highest collection efficiency 83.4% and 83.3% of 2018.

Table 17: NERC ATC&C Losses (%) Target and Performance by DISCOs

DISCOs	MY TO Target (%) for 2018	Average ATC & C 2018/Q3	2018/ Q2
Abuja	22.33	36.63	47.19
Benin	23.91	52.84	52 36
Eko	11.22	30.77	30.13
Enugu	20.56	54.68	56.21
Ibadan	19.67	51.62	51.66
Ikeja	10.81	30.56	32.96
Jos	39.12	63.77	72.07
Kaduna	11.47	66.05	67.70
Kano	22.06	50.92	50.70
Port Harcourt	29.70	63.60	64.21
Yola	23.71	68.57	70.39
MY TO Level Average ATC&C Losses	**21.71**	**51.91**	**54.24**

Table 17 also shows Port Harcourt ATC&C losses as high as 63.30% and 64.21% compared to Eko with ATC&C losses of 30.77% and 30.12% in the subject period.

4.2 Simulation Result

The simulation is carried run with calculated load demand, appliance capacities and usage as shown in Tables 6 to 8. The result of the simulation using Python and EA is summarized in Table 18.

Table 18 Simulation Result Showing a Comparison between Estimated Bill Cost and Metered Bill

S/No	Apartment Type	Annual Estimated Bill	Annual Metered Bill (Naira)	Difference (Naira)
1	One room	30,000	113,179	83,179
2	Self-contained	36,000	218,664	182,664
3	One bedroom	60,000	421,940	361,940
4	Two bedrooms	96,000	631,421	535,421
5	Three bedrooms	144,000	868,700	724,700
6	Annual Loss	366,000	2,253,904	1,920,625

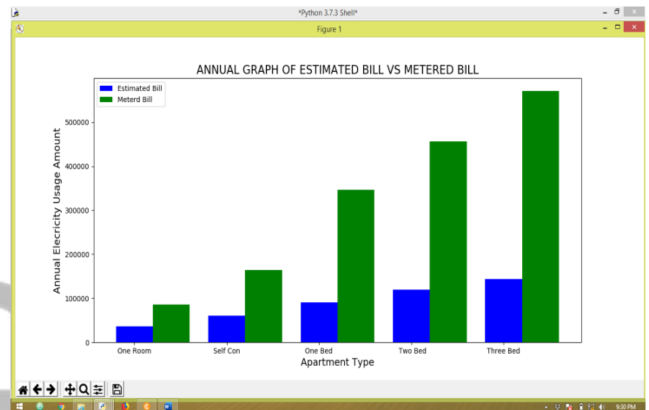

Fig. 2: Annual Graph of Estimated Bill against Metered Bill

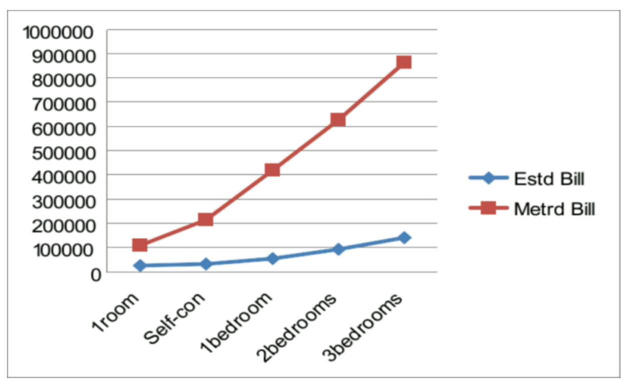

Fig. 3: Comparison Graph of Estimated Bill against Metered Bill

4.3 Discussion of Results

Table 11, Figs. 2 and 3 show the optimal solution for an improved electricity billing and the values show the substantial difference between estimated bill in which consumers pay less than 50% of actual power consumption and smart metered bill in which consumers are made to pay up 99% of actual power consumption. The calculated losses are shown for the different apartment sizes and total annual loss calculated as 1,920,625Naira. From the above test case, it is clear that the developed algorithm using Python is effective in producing improvement in the billing method of PHED.

5.0 CONCLUSION AND FUTURE WORK

This study presented an optimized electricity billing method by making use of a new optimization approach for optimal smart meter implementation in power distribution using python. The python program presented in this study has remarkable superiority in computation speed and convergence speed compared to the other optimization methods.

Aligning the objective functions and solving the optimization problem by installing smart meters and python applied on EA, billing performance has been greatly increased. The simulation results show a considerable high improvement in the billing performance above 50% thereby yielding a remarkable revenue collection increase. It is important to mention that from the different reports as presented by this dissertation which had shown possible gaps in performance of Port Harcourt Electricity Distribution and the accumulated energy and revenue losses, the method implemented in this work has the potency to reverse the situation. The results show clearly the improvement that can be made in revenue collection and thereby reducing the loss and improvement in ATC&C performance.

5.2 Contributions to Knowledge

The major contributions to knowledge from this work are:

a) The compensation is yielding into increase in revenue collection, loss reduction and overall performance of billing.

b) The application of Python on evolution algorithm is effective in optimizing billing method.

5.3 Recommendations

The consideration for this work was limited to residential customers in one room, self-contained, one bedroom, two bedrooms and three bedrooms apartment respectively. I therefore recommend that in this coverage location of study or any other locations, bigger consumer buildings and commercial buildings should be considered.

A major issue observed in this study is that the time of use of energy is not taken into consideration in the present billing methods, both in estimated and metered billings. However, since the smart meters measure and communicate readings on regular basis, the tariff can be in two parts – for peak and off peak periods. With proper education of consumers, it will assist in energy consumption pattern.

Time of use based tariffs will lead to better management of energy – where installations with high inductive loads may choose to run more during off-peak periods thereby saving costs.

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