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PHASE-CONSTRAINED BILLING SCHEME FOR DEREGULATED ELECTRICITY INDUSTRY IN NIGERIA

Ogu, George Emenike[*1], Dike, Damian [2], Paulinus-Nwammuo, Chiedozie[3] & Adinfono, Moses[4]
[*1,3&4]Postgraduate Students and Assoc. Professor
[2]Department of Electrical and Electronic Engineering, Federal University of Technology, Owerri, Imo State, Nigeria

ABSTRACT

In Nigeria, consumers resort to spontaneous change phases whenever there is power outage in any of the three phases that service their single phase meters. This lead to service transformer overload with severe consequences to domestic electrical appliances, utility firm equipments, loss of revenue due to down time and in a few cases lives. In order to reduce the frequency of these changes, a phase-constrained electricity-billing scheme for the deregulated Nigerian Power Industry was developed. This was done by re-arranging the service lines and setting up constraint matrices to relate the phase and service lines utilizable by customer to the electricity bill using penalty factors. Based on this, an algorithm with accompanying flowchart was developed; and implemented using a script file written in MATLAB environment. Results obtained for the residential (R2) class indicated that the percentage changes from the unconstrained bill to the constrained bill are 4.3% reduction for one line users, 8.6% increase for two lines users, 21.6% increase for the three lines users in the single phase category and 29.4% increase for the three phase, three lines users in the proposed system. Application of the model could help electricity regulatory authorities implement a fairer electricity billing system.

Keywords: *Customer Classes, Likert Scale, Mean Base Analysis, Penalty factor*

I. INTRODUCTION

Electric energy meter is the direct billing interface between utility grid and consumers; and has undergone several advancements in the last decade. In Nigeria, electricity billing commenced from the initial use of post-paid meters. In post-paid system, there is no controlled use of electricity from the consumer's side. Power wastage on the consumer's side is high, due to lack of efficient planning of electrical consumption. Meter readers go from house to house to check consumer energy usage after which bills are prepared. Hence, the post- paid system is characterized by inconsistent billing arising from high billing error estimates. An inconsistent billing system leads to constant complaints by consumers, low consumer satisfaction, and hence poor public perception of service providers. The aftermaths of these are uncontrolled loss of revenue.

The problems of unstable, inadequate and unreliable power supply in Nigeria has been linked to the power sector's inability to generate enough revenue to cover its operating costs let alone its huge capital expenditure requirements [1]. At the heart of this problem lies the method employed in service drop to residential buildings in Nigeria. A utility-approved single phase or a three -phase service drop is normally wired to residential buildings according to the types and capacities of loads intended to be powered, with the applicable billing meter (single-phase or three-phase meter) wired in. Nevertheless overtime, experience shows that this is no longer the norm, as today almost all residential buildings are serviced by three-phase drop, with or without a single-phased meter. Residential buildings rarely install a three-phased meter. Now if a fuse of a powered substation transformer suddenly trips for any other reason such as phase overload, earth fault, line fault, etc. the residential consumers connected to that phase quickly and in a frenzied manner change or transfer their phases to the next available phase, from their own installed three-phase service fuse cut-out ports. Due to current surge on that very phase, the line fuse located in the feeder pillar soon trips to clear that feeder. Next all consumers transfer their loads to the next available phase. The feeder fuse then trips in a shorter time. This consumer attitude continues until all feeders' fuses go out and a total area blackout results. The results of the frequent and cyclical phase changing by residential consumers are: frequent distribution

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transformer and phase/feeder fuses breakdown, unreliability and unavailability of supply (brown-outs, black-outs), unnecessary revenue and man-hour losses, frequent intervention calls by consumers, disputes over bill payments, service disconnection and reconnection problems by utilities, etc., which eventually portrays the utilities in bad light. Cost recovery simply means recouping what was invested in providing services. Cost recovery is closely related to tariff. Tariffs imply payments made by electricity consumers. They are streams of revenue from the users that would enable investment cost to be recovered [2]. Tariff in the power sector may be defined as the aggregate price paid by the final consumer of electricity. Tariff collection enables the provider of electricity whether public or private investor to recover costs of energy consumed. Obviously the public sector finances invested in electricity supply are provided from tax payers' money and other sources of Government revenue. To ensure continued supply of the service and long-term sustainability, there is the need to recover all costs associated with the power service.

Presently, there has been an increasing desire to install digital pre-paid meters to bill consumers according to their consumption. It automates the meter reading, carries out prepaid recharging function and enables the exchange of consumed data information between the grid and consumer. Details of customer consumption information sent by the prepaid energy meter may be stored in the grid computer for future verification [3]. Electricity supply disconnection is achieved when the preloaded credit is exhausted. Electricity billing system, in residential applications could be realized with either of single phase or three phase energy pre-paid meters. Considering that over 60% of utilities customers fall within the residential R2 class that significantly affects the revenue collection of utilities companies, effective, accurate and reliable means of collecting it must be followed. The electricity energy meter and system of billing is very critical to cost recovery and sustainability of service in terms of quality, convenience and continuity of service. In this 21st century, electric utility management, public utility regulators and energy consumers have realized the need to have an economical and effective way of achieving satisfactory reliability levels of electric service. To realize this objective, a system must be engineered to provide the type of reliability needed at the lowest possible cost [4-5]. It is easy to invest in distribution capacity, but recouping that which was invested is of paramount importance as every business was started in the first place for profit, which in turn is re-invested for further capacity expansion. Hence, the mode and manner of billing electric energy consumers is at the heart of failure or success of power distribution companies.

Various research works have gone into improving the power system in terms of management, billing, tariff plans and so on. Some researchers have considered the application of a new Multi-Year Tariff Order to improve revenue generation [1], the design and introduction of Power Billing System (PBS) with online capabilities for better administrative purposes [6], and the development of microcontroller based automatic trip control system for energy management using GSM wireless technology [7]. Research activities have also gone into the development of automated energy metering systems capable of remotely monitoring and controlling the distribution company's database [8], and **state-of-the-art utility billing software known as "Utility Billing software – *u*Vision**®" [9]. The effect of voltage unbalance on the operation and performance of three-phase distribution transformer has also been investigated [10]. Questionnaire-based surveys have been carried out to evaluate electricity supply, state of billing meters [11], as well as establishment of factors that contribute to the convenience offered by the prepaid billing system as opposed to the post-paid system [12]. In this work, reference was made to relevant rates and billing categories in [13-15].

This research therefore seeks to establish that a billing system that is phase-constrained will make for a reliable and available electricity supply that would eliminate the trouble of panic phase changing by electricity consumers

II. METHOD & MATERIAL

1. Modeling of Phase-Constrained Billing Scheme

It is desired to model a phase constrained billing system that generates electricity bills for consumers based on the number of phases they bring into their residences. We foresee that such a system could improve the availability, reliability and possibly the lifespan of the neighbourhood distribution substation transformer by systematic

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manipulation of customer behaviour through the service line connections and billing. Fused links depict the power flow path to the billing meter. Fig. 1 illustrates the phase-constrained billing scheme.

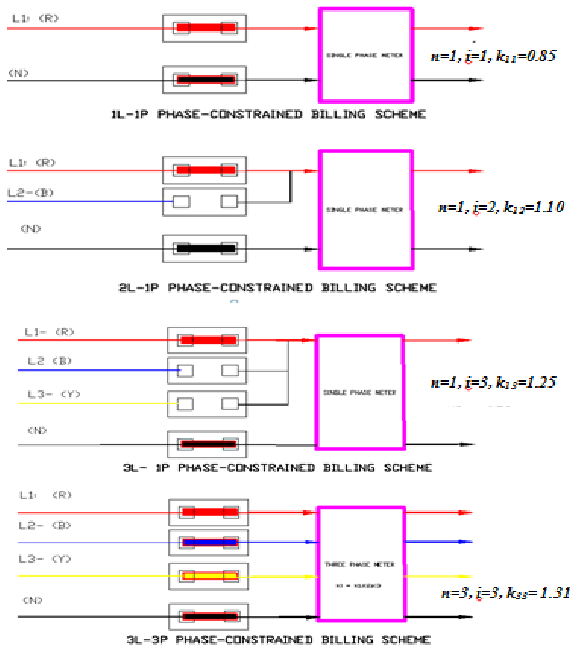

Figure 1: Phase-constrained billing scheme

From first principle, the exponential forms of energy consumed, $\boldsymbol{E_c}$ and the basic energy consumption cost, $\boldsymbol{E_{cc}}$for a composite load are respectively written as:

$$\boldsymbol{E_c = nIVTe^{j\theta}} \qquad (1)$$

$$\boldsymbol{E_{cc} = nIVTR_t e^{j\theta}} \qquad (2)$$

By combining some of the cost parameters defined in Table I as stipulated by electricity market regulators and decomposing the complex exponential operator using Euler's theorem, the electricity cost model (BILL) for the phase-constrained billing scheme (3) is obtained:

$$\boldsymbol{BILL = (1 + R_v)(nk_{ni}IVTR_t \cos\theta + F_c) - C_{mr} + (1 + \alpha)A_{rr}} \qquad (3)$$

Applicable parameters, symbols, dimensions and limits employed in the billing scheme are defined in Appendix 1.

2. Research Survey Method

Since it is thought that having more than one phase of electric supply to residential buildings significantly contributes to overloading of distribution transformer, resulting from frequent phase-changing; it is then necessary to sample customers' attitude, awareness and satisfaction in a bid to seek for ways of introducing customer-side load management.

Analysis of respondents' data was completed as follows:

a. A total of three hundred structured questionnaires was prepared and distributed to electricity customers within the location of transformer substations.
b. Frequency Distribution Table was prepared from the returned respondent(s) data, and analysed using descriptive statistics.
c. Questionnaires were analysed based on the weighted mean in (4), as a measure of central tendency to assess the degree of influence of each factor.

The Mean Base Table, based on the 5-point Likert scale [16] was adopted as the method of respondent data analysis [17], with scales defined as follows: Strongly Agree (SA): 5; Agree (A): 4; Neutral (N): 3;Disagree (D): 2; Strongly Disagree (SD): 1.

The mean values are computed using (4) and (5):

$$\bar{X} = \frac{\sum f_i . X_i}{N} \quad (4)$$

$$\overline{X_g} = \frac{\sum \overline{X_i}}{N} \quad (5)$$

Where: i: rank of scale from 1 to 5; X_i: weight of respondent's answer choice; $\bar{X}$: weighted mean for a Likert item;

$\overline{X_g}$: Mean Average for a given group of hypothesis; f_i: response count or frequency; N: frequency/count.

III. IMPLEMENTATION

(A) Simulation Algorithm

The following steps are involved in the actualization of the phase-constrained billing system for deregulated power system.

a) Initialization: Initialize energy charge (E_c), energy consumption charge (E_{cc}), and CAPMI refund (C_{mr}) and current month arrears (A_{cr}).
b) Input data values: Number of Phases (n), No. of Service Lines (i), Phase-Constrained Penalty Factors (k_{ni}), Energy Consumption (IVT), Tariff Rate (R_t), Previous Month Arrears (A_{rr}), Fixed Charge (F_c), VAT rate (R_v), Power Factor ($\cos\theta$), Monthly Incremental penalty factor on Arrears (α) and Arrears Severance Factor (β).
c) Read Number of Phases (n) and Number of Service Lines (i).
- Check if 'match' is correct according to defined constraints.
    - 'Yes'. Apply matching penalty factor k_{ni} of constraint matrix. Go to (d).
    - 'No'. Display Error message: **'Service Line / Phase Mismatch!'End**.

d) IF phase, n = 1 AND service line, i = 1, apply penalty factor, k_{11}.
- Perform block 1. Then compute Arrears Allowable Margin, **AAM**.

e) Read **C**$_{mr}$. Check IF it is ZERO. 'Yes'. Set CST3 to CST2. 'NO'. Perform block 2.
f) Check IF **A**$_{rr}$ is ZERO. 'Yes'. Set CST4 to CST3. **Output BILL = CST4**. **End**.
'No'. Perform block 3.
g) Then Compare **A**$_{cr}$ and **AAM**. Is **A**$_{cr}$>**AAM**? 'Yes'. Display Error message: **'Disconnected! Clear Arrears.'** 'No'. Perform block 4. **Output BILL = CST4**. **End**
Else continue to (i).
h) IF n = 1 AND i = 2, apply penalty k_{12}. Repeat (e) to (h). **End**. Else continue to (j).
i) IF n = 1 AND i = 3, apply penalty k_{13}. Repeat (e) to (h). **End**. Else continue to (k)
IF n = 3 AND i = 3, apply penalty k_{33}. Then Repeat (e) to (h). **End**

(B) Simulation Flowchart

Fig. 2 as presented in Appendix 2 describes the various loops and parameters employed in the flowchart utilized in the implementation of phase-constrained billing scheme.

(C) Implementation Data

The data used in the simulation was obtained from [1] and is reproduced in Table II of Appendix 3.

IV. RESULT & DISCUSSION

(A) Bill Results

The results obtained from the simulations performed are contained in Tables III to Table VIII are presented in Appendix 4.

The BILL results for customer classes R2, C1, D1 and A1 at different power factor values are presented in Table III to VI. Table VII summarizes all customer classes for $\boldsymbol{k_{ni}} \neq \mathbf{1}$ and pf = 1, compared with the unconstrained bill when $\boldsymbol{k_{ni}}$ and pf are both set to 1.

Table VIII compares and summarizes the constrained and unconstrained bills of various customer classes for 1 to 3 electric lines service at unity power factor.

(B) Result of Field Survey

Analysis of the field survey showed that the ages of respondents were at least 30, and were either self – employed, civil servants or employees of private companies. For 300 questionnaires distributed, males and females respondents were 128and 90respectively, yielding a total response rate of 72.7%.

The following results were obtained by statistical evaluation of the mean based on collected data from field survey.

i. ***Group A: Frequent phase changing attitude by respondents creates feeder unbalance.***
The group average mean integer value of 3 (actual = 3.26), signifies that respondents were largely indifferent to this concept. Hence they remained neutral (N) in A1, A2, A3, A7 and A8. Respondents disagree (D) in A4, rejecting increased bill for bringing in or retaining multiple electric service lines. They also disagree (D) in A6 that "phase changing is the right action to perform". However, respondents agree (A) in A5 implying that if the 1-electric service line they bring into their residence is stable and 'cheaper', it would be preferred to having or retaining multiple lines.

ii. ***Group B: Phase constrained electricity supply will reduce phase unbalance problems and increase availability and reliability.***
Group average mean integer value of 4 (actual = 4.20) implies that consumers agree that phase constrained supply could mitigate substation problems brought about by consumers' actions. Hence they agree (A) in B9, B10, B11 and B12.

iii. ***Group C: Utilities' attitude (slow response and inconsistent billing) encourages sharp practices.***
A group average mean integer value of 3 (actual = 3.33) implies neutrality (N) of consumers to this hypothesis. Respondents agree in C13 that lack of prompt response by utilities workers encourage sharp practices, but disagree (D) in C14 and C16 signifying that electricity bill is still a grey area. Respondents remain neutral (N) in C15 despite that a greater percentage (37.6%) disagrees, as they have to pay their bills all the same.

iv. ***Group D: Unenforced or absence of applicable legislation(s) contributes to phase imbalance.***
Being a policy matter, a group average mean integer value of 3 (actual= 3.71) shows that respondents are largely neutral (N) or indifferent to this hypothesis. The Likert scale weighted mean of D17 is neutral (N) despite that 38% of respondents strongly agree (SA). Respondents disagree (D) in D18 implying that it is better to call utility workers for intervention.
However, respondents agree (A) in D19 and D20 that tampering with electricity installations must be seriously addressed.

(C) Discussion of Results

The BILL of various customer classes were computed with the MATLAB program using TABLE II and results were presented in Tables III to VII. The results show that customers connecting to 1 or 2 lines have reduced bills based on

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the prevailing charges. The BILL in each case is proportional to the power factor value of the composite load. It is seen from the computation that maintaining only 1 service line has an incentive of reduced bill attached to it. If customers can have the guarantee of quality service with 1 line at a reduced bill as indicated in the tables, there may be no need to have 2 or 3 lines. If the billing system is constrained as such, it is considered that the distribution system availability will improve as occasions of frequent phase changing and resultant overloading of distribution transformers will be minimized.

Table VIII summarizes the unconstrained BILL for various customer classes at ***unity*** power factor by ignoring the phase constraints which is actually what the utilities do. They also charge customers at unity power factor and advice that customers improve their power factor to near unity in order to reduce the load on the distribution transformer. Evaluation of the Table 4.6 shows that for the residential R2 class, the percentage changes from the unconstrained bill to the constrained bill are 4.3% reduction for 1- line users; 8.6% increase for the 2-line users; and 21.6% increase for the 3-lines user in the single-phase category. Conversely, a bill increase of 29.4% was noted for the 3-phase, 3-lines residential customer in this proposed billing regime. Similar computations apply for the customers in the other classes. Therefore, connecting to 2 or 3 service lines has a penalty attached to it with the consequence of higher bills.

From Tables III to VIII, it may be deduced that it is cost effective for a customer of a given class to maintain a single line electric service in view of incentive of better service at reduced bill. Where the 1-line service is inadequate to support the loads, it becomes the customer's choice to apply for service upgrade at his own expense. The result of the field survey in Section 4.2 corroborates the bills presented in the results as shown in Section 4.1. Evaluation of Section 4.2, Group 'A' result shows that the desire of customers is to have quality power supply without minding how they get it. They are indifferent and so do not consider the impact of their actions on the operation and service life of the distribution transformer as well as the operating costs to utility.

Evaluation of Section IV (B), Group 'B' result shows that customers are prepared to align with controlled measures to tackle unbalance and overload issues provided that reliability and availability of distribution transformer power supply is assured, in view of incentives of 1- line electric service supply.

Evaluation of Section IV (B), Group 'C' shows that sharp practices among utility staff regarding inconsistent metering, slow service delivery, poor work ethics, etc. can cause consumer apathy. This could lead to incidence of frequent phase changing, unbalance and overloads, thereby impacting negatively on utility's revenue.

Evaluation of Section IV (B), Group 'D' indicates that regulatory bodies and utilities must actively legislate and enforce laws that will discourage tampering of utility installations. Consumers do not need to tamper with reliable and available installations.

V. CONCLUSION

A phase-constrained electricity billing system was developed using constraint matrices to relate the number of phases and number of service lines utilizable by customer to the electricity bill using penalty factors. The developed algorithm and flowchart were implemented using MATLAB script file.

Results obtained for the residential (R2) class indicated that the percentage changes from the unconstrained bill to the constrained bill are 4.3% reduction for one line users, 8.6% increase for two lines users, 21.6% increase for the three lines users in the single phase category and 29.4% increase for the three phase, three lines users in the proposed system. These implied that bill reduction for single line customers and bill increase for multiple lines customers.

Proposed Model was validated using results realized from statistical evaluation of customer behavior and utilization index based questionnaire responses obtained from a field survey. Responses from actual customers indicated their willingness not to change their phases if there would be regular power supply. For others with enhanced income, they will be ready to pay higher for consumed electricity to have a second phase incoming to serve as backup in case one phase may cut due to the age of these lines.

Application of model could help Regulatory bodies and related authorities implement a fairer utilization based electricity metering and billing system. It will also help to reduce the frequency of electricity consumers changing from one phase to another thereby reducing overloading of service transformers with their attendant consequences. In very few cases where one than two phases come into a single-phase metered customer residence, the local utility firm will be aware of this and include such cases in the load allocation and management.

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APPENDICES

Appendix 1

Table I: Nomenclature for phase-constrained electricity billing scheme

S/N	Parameter	Symbol	Dimension	Remarks
1	Number of Phases	n	Nil	$n = 1$ or 3
2	Number of Electric Service Lines	i	Nil	⊺Reg.
3	Energy Consumption	E_c	KW.h	≥ 0
4	Energy Consumption Charge	E_{cc}	Naira (N)	≥ 0
5	Power factor (pf)	$\cos\theta$	Nil	$0.70 \leq pf \leq 1.00$
6	Value Added Tax (VAT)*	R_v	%	5
7	Tariff Rate*	R_t	N/KW.h	MYTO II, 2012
8	Credited Advance Payment for Metering Implementation (CAPMI) Monthly Refund*	C_{mr}	Naira (N)	≥ 0
9	Monthly Asset Recovery Fixed Charge*	F_c	Naira (N)	MYTO II, 2012
10	Previous Month Arrears	A_{rr}	Naira (N)	≥ 0
11	Current Month Arrears	A_{cr}	Naira (N)	≥ 0
12	Arrears Allowable Margin	AAM	Naira (N)	≥ 0
13	Phase Constrained Penalty Factors⊺	k_{ni}	Nil	k_{11}=0.95, k_{12}=1.10, k_{13}=1.25, k_{33}=1.31
14	Monthly Incremental Penalty Factor on Arrear ⊺	α	%	$1.0 \leq \alpha \leq 3.0$
15	Arrear Cut-Off Factor⊺	β	Nil	$0.5 \leq \beta \leq 2.5$

Legend: Reg. = ⊺ Regulatory Body Approval Required * [1].

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Appendix 2: BILL Simulation Flowchart

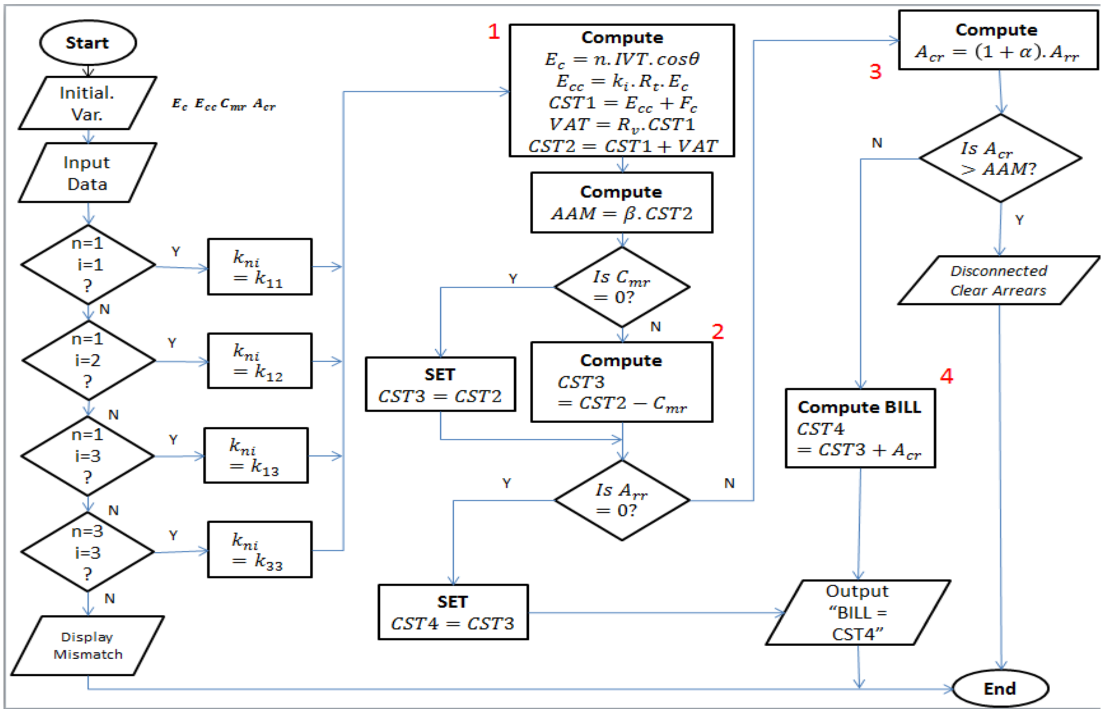

Figure 2: BILL Flowchart

Appendix 3: Implementation Data:

Table II: Billing Scheme Implementation Data for various Customer Classes

CLASS	R_v	n	k_{ni}	IVT (KWh)	R_t	pf	F_c	C_{mr}	A_{rr}	α	β
R2	0.05	1	0.95, 1.10, 1.25	250	16.44	0.75 – 1.00	650	0	0	0	0
C1	0.05	1	0.95, 1.10, 1.25	250	18.14	0.75 – 1.00	650	0	0	0	0
D1	0.05	1	0.95, 1.10, 1.25	250	18.45	0.75 – 1.00	1300	0	0	0	0
A1	0.05	1	0.95, 1.10, 1.25	250	20.21	0.75 – 1.00	650	0	0	0	0
3 Phase	0.05	3	1.31	250	16.44, 18.14, 18.45, 20.31	0.75 – 1.00	650, 650, 1300, 650	0	0	0	0

Appendix 4: Simulated Results

Table III: Residential (R2) Bill Result

No. of Service Lines, i	Phase Constrained Factor, k_{ni}	Power Factor, pf					
		0.75	0.80	0.85	0.90	0.95	1.00
		Bill (=N=)					
1	0.95	3757.30	3962.30	4167.30	4372.30	4577.20	4782.20
2	1.10	4242.80	4480.10	4717.50	4954.80	5192.20	5429.60
3	1.25	4728.30	4998.00	5267.70	5537.40	5807.20	6076.90

Table IV: Commercial (C1) Result

No. of Service Lines, i	Phase Constrained Factor, K_{ni}	Power Factor, pf					
		0.75	0.80	0.85	0.90	0.95	1.00
		Bill (=N=)					
1	0.95	4075.20	4301.40	4527.60	4753.80	4980.00	5206.20
2	1.10	4610.90	4872.80	5134.70	5396.60	5658.50	5920.40
3	1.25	5146.60	5444.30	5741.90	6039.50	6337.10	6634.70

Table V: Industrial (D1) Bill Result

No. of Service Lines, i	Phase Constrained Factor, K_{ni}	Power Factor, pf					
		0.75	0.80	0.85	0.90	0.95	1.00
		Bill (=N=)					
1	0.95	4815.70	5045.80	5275.80	5505.90	5735.90	5966.00
2	1.10	5360.60	5626.90	5893.30	6159.70	6426.10	6692.40
3	1.25	5905.40	6208.10	6510.80	6813.50	7116.20	7418.90

Table VI: Special (A1) Bill Result

i	K_{ni}	Power Factor, pf					
		0.75	0.80	0.85	0.90	0.95	1.00
		Bill (=N=)					
1	0.95	4481.10	4734.30	4987.60	5240.80	5494.10	5347.30
2	1.10	5080.90	5374.10	5667.30	5960.60	6253.80	6547.00
3	1.25	5680.70	6013.90	6347.10	6680.30	7013.50	7346.70

Table VII: Bill result for three phase supply with three phase meter

Class / Pf	0.85	0.90	0.95	1.00
Residential (R2)	15098.00	15187.00	16794.00	17642.00
Commercial (C1)	16589.00	17525.00	18460.00	19396.00
Industrial (D1)	17543.00	18495.00	19447.00	20398.00
Special (A1)	18492.00	19540.00	20587.00	21635.00

Table VIII: Bill summary for customer classes R2, C1, D1 and A1

i	K_{ni}	Pf	R2	C1	D1	A1
Unconstrained Bill (=N=) with K_{ni} =1, pf = 1)						
	Single Phase (n=1)		4998.00	5444.25	6208.13	6013.88
	Three Phase (n=3)		13629.00	14967.75	15894.38	16676.63
i	K_{ni}	pf	Constrained Bill (=N=)			
1	0.95	1.00	4782.20	5206.20	5966.00	5747.30
2	1.10	1.00	5,429.60	5920.40	6692.40	6547.00
3	1.25	1.00	6,076.90	6634.70	7418.90	7346.70
3	1.31	1.00	17,642.00	19396.00	20398.00	21,635.00