American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-10, Issue-03, pp-54-62
www.ajer.org
Research Paper Open Access

Effects of Prepayment Meters in the Low Voltage Distribution Network and On Electrical Energy Consumption in the City Of Kinshasa.

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Abstract: *In this article, we present the technological and economic effects of prepayment meters by the different mathematical methods allowing to determine the dynamic behavior of the electrical network and to model the parameters of electrical energy consumption. The developed equations address the issue of electricity consumption by subscribers in the domestic sector.*

These methods are performed on low voltage subscribers who use prepayment meters; whose cost per kilowatt hour is variable in Congolese Francs.

The objective: of this article is to improve the load rate of substations in the city of Kinshasa and explore the financial viability of electric energy consumers using prepayment meters. This consists of identifying the electrical charges in the domestic sector from the measurements made at the level of the electrical energy meter. The problem therefore comes down to identifying the consumption of one or more electrical devices and classifying them by group of loads. Financial sustainability in the electricity sector shows near-budget deficits and hidden costs from subscribers using the electricity grid.

Keywords: *bills exchange, prepayment meters, distribution network. low voltage, consumers. electric energy.*

Date of Submission: 23-02-2021 Date of acceptance: 07-03-2021

I. INTRODUCTION

Many countries have started a process of migrating the fleet of low voltage electricity meters to a generalized remote reading or remote management system. Thinitiatives aim to deploy meters with extended functionality, including remote index transmission, remote load curve transmission, remote power shutdown and contract power change.

The low voltage electrical network in household use, largely is in the single-phase system. Even if the distributor tries to distribute them in a three-phase system for certain households with significant consumption. Billing on electricity consumption is becoming a concern due to the increasing use of prepayment meters, but also to the application of the cost of kilowatt-hour which limits all major electrical loads from subscribers.

Indeed, the calculation of the power subscribed by the subscriber and the index of electricity consumption in the low voltage distribution network does not reflect the reality in the use of prepayment meters. In addition, the maximum current of these single-phase and three-phase meters are in forty to fifty percent of a household's load. This justifies the damage to the several prepayment meters when a household is operating at seventy or eighty percent of its load.

I.1 LOAD NATURE OF A MENAGE

In a household, appliances are divided by three types of load, resistive, inductive and capacity. Electricity consumption depends on these natures of the charges. It is a question of developing the equations of the impedance and admittance of a household to regulate the financial viability in the consumption of electrical energy.

I.1.1 Electricity consumption models

if we consider a start date t1 and an end date tn, separated by n – 1 intervals (ηϵN+*) of duration equal to the constant time step Δt∈ R+*, the power consumption in this period will be:

$$\{P(t_i)\boldsymbol{i} \in (1,2,..,n-1)\} \qquad (1.1)$$

With P (ti) the average electric power during the interval [ti, ti+1[(of duration Δt) considered. In the following, we use P to denote electrical consumption, by implying that we have defined a start date, an end date and a time step. When it is written “consumption”, without further precision, we refer to the electricity consumption.

I.1.2 Spatial component

Electricity consumption, like any power, is additive. In this brief, we do not take into account losses on the electrical network. With these assumptions, understanding electricity consumption means knowing the consumption of all loads. Concretely, the elementary loads connected in parallel on the network are the customers.

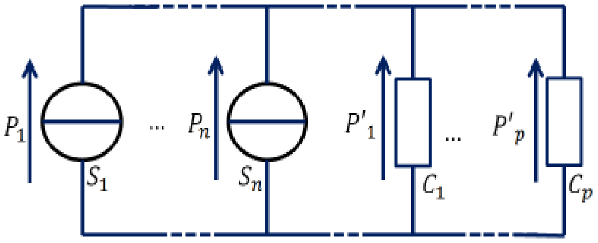


Fig 1.1: Diagram of electricity consumption, power sources and loads whose consumption is added.

I.1.3 Electricity consumption of a zone

If the problem is posed formally, and will follow throughout this in-depth study thesis, the power consumption Pz of a zone z will be:

$$P^z = \sum_{j\epsilon J^z}(P^j) \qquad (1.2)$$

With Pj the electricity consumption of customer j and Jz all customers in the area. Each customer j has a set of electricity consuming devices Apj. A customer's consumption is therefore expressed by:

$$P^j = \sum_{a\epsilon Ap^j}(P_a) \qquad (1.3)$$

With Pa the consumption of the device a. If we use equations (2.2) and (2.3), we have:

$$P^z = \sum_{j\epsilon J^z}\sum_{a\epsilon Ap^j}(P_a) \qquad (1.4)$$

When measuring the electricity consumption of customers, we realize certain similarities in their consumption profiles.

The different customers can be grouped into a set K of different categories. The consumption of the zone will then be:

$$P^z = \sum_{k\epsilon k}\sum_{j\epsilon J_K{}^Z}(P^j) \qquad (1.5)$$

With JK^Z the set of customers in zone z belonging to category k.

If we denote by C the set of all types of devices, C a given type of device, Apzc the set of devices of a type c in zone Z, has a given device. We then have the consumption of the zone which is worth:

$$P^z = \sum_{c \epsilon C} \sum_{a \epsilon AP_c{}^z} (P_a) \qquad (1.6)$$

I.1.4 Electricity consumption of a zone

Power consumption of a Pz zone. This is the power consumption measured over a certain spatial area. Power consumption of a zone and a type of Pzc devices. This is the aggregate power consumption of an area but only of one type of device. They are often calculated from a penetration rate by type of device in the area where, when it comes to temperature sensitive uses, it is broken down using temperature data. We then have:

$$P_Z = P_{Cuis} + P_{ECS} + P_{EP} + P_{Clim} + P_{Autre} \quad (1.7)$$

Power consumption of a type of Pzk customers. This is the power consumption of different customers only of the same type. We have:

$$P_Z = P_{résidentielle} + P_{tertiaire} + P_{industrielle} \qquad (1.8)$$

Specific electricity consumption in the residential sector has thus doubled in 20 years, with an average growth of 44% per dwelling between 1990 and 2012.

II. METHOD OF CALCULATING THE POWER OF A ZONE

II.1 Zone without prepayment meters

II.1.1 Analysis of the power of an LV substation

The power of the departures of a station is relative to the expression (1.7) of the zone gives:

$$P^Z{}_{dep\ A} = 91000 + 3880 + 12270 + 1200 = 107150\ W$$

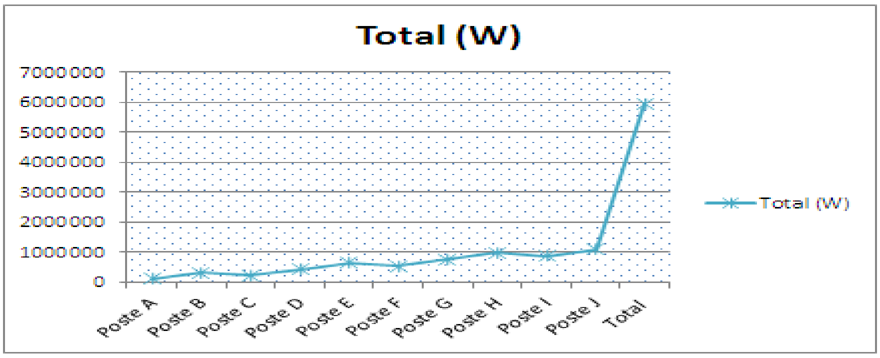


Fig II.1: Evolution of load in the substations

II.1.2 Calculation of load rates

The evolution of the load rate makes it possible to monitor the variations in the power of the LV substation, it allows the network operators to limit the inrush of the higher current, which leads to the load shedding system for the cooling of the transformer. The formula for calculating the transformer load rate is therefore:

$$T_{Xtfo} = \frac{S_Z}{S_{ntfo}} \text{x } 100 \qquad (2.1)$$

The charge rate values are within the range of the IEC standard, but tend to increase with increasing operating time. Because in non-prepayment mode, the energy is managed by the distribution network.

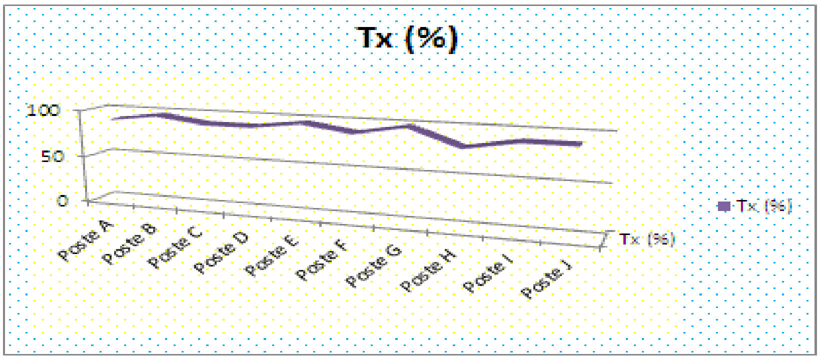


Fig II.2: simulation of changes in the rate of charges

II.1.3 Calculation of the determination of the overload rate

The load power (Pch) is the highest value of the power reached by the station at a time. It is obtained when all outlets are in service and all subscribers are connected. It is expressed by the relation:

$$\mathrm{P_{ch}} = \mathrm{K_{dep}K_{ch}P_Z} \qquad (2.2)$$

Power overload; this is the operating power of the zone beyond the maximum power that the distribution network must provide. This power is generally greater than or equal to the power of the distribution network; it is obtained from the charging power and it is scalable over time.

$$P_{SCH} = P_{ch}.K_{sch} \qquad (2.3)$$

However, the overload coefficient is the ratio between the coefficient of departures over the coefficient of subscribers. The overload coefficient is obtained from the following expression:

$$K_{sch} = \frac{K_{dep}}{K_{ch}} \qquad (2.4)$$

By replacing the overload coefficient by its expression, the overload power becomes:

$$T_x = \left(P_{ch}.\frac{K_{dep}}{K_{ch}}\right) / \frac{P_{tf}}{100} \qquad (2.5)$$

$$T_x = \left(112{,}7.\frac{0{,}9}{0{,}85}\right) / \frac{125}{100}$$

$$T_x = 94{,}7\ \%$$

This equation translates the expression for the variation of the power of a zone; the simulation in Matlab shows that for a period of operating time, the overload power varies over the interval from 94% to 103%. An operating rate close to the overload limit.

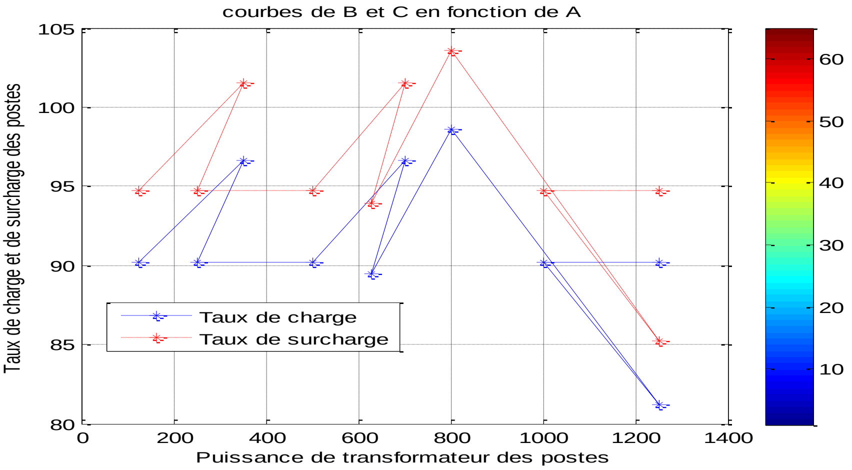


Fig II.3: simulation of overload rate

II.2 Zone with prepayment meters

Each subscriber is responsible for his consumption; the rate of consumption is recorded on the reference value of the receivers. Note that with regard to households, the consumption values correspond not to the equipment, but to the average power of the equipment. So consumption for households take into account the specific operating time.

II.2.1 Calculating the Before-Noon charge rate

The output power of a station in the zone depends on the expansion coefficient;

Figure II.3: simulation of overload rate

II.2.2 Zone with prepayment meters

Each subscriber is responsible for his consumption, the rate of consumption is recorded on the reference value of the receivers. Note that with regard to households, the consumption values correspond not to the equipment, but to the average power of the equipment. So consumption for households take into account the specific operating time.

II.2.3 Calculating the Before-Noon charge rate

The output power of a station in the zone depends on the expansion coefficient; this power is obtained from the following expression:

$$P^{Z}{}_{fdep} = (P_{Blanc} + P_{TIC})x\, k_f \quad (2.6)$$

II.2.4 Calculation of the Afternoon load rate

In the afternoons, the power equation for departures from a station in the zone takes into account high power receivers; it is defined below:

$$P^{Z}{}_{fdep} = (P_{Cuis} + P_{TIC} + P_{Blanc}) \, x \, k_f \quad (2.7)$$

II.2.5 Calculation of night load rate

In the evening or at night, the power equation of the outputs from a station in the zone takes into account low-power receivers; this power is defined below:

$$P^{Z}{}_{fdep} = (P_{TIC} + P_{Ec}) \, . k_f \qquad (2.8)$$

II.2.6 Simulation of the daily cycle

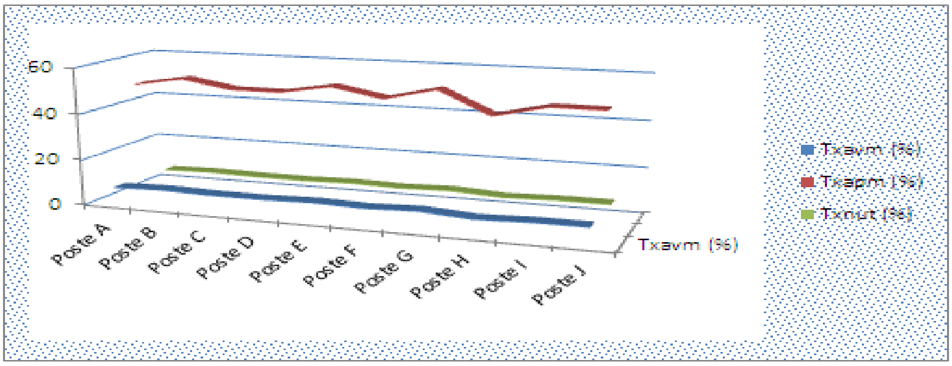


Figure II.4: Simulation of the daily cycle

The daily cycle with prepayment shows that, electricity consumption varies at a low rate in the mornings, justified by the hours of crisis (high power appliances and lighting circuits are out of service). Then a sharp rise towards average consumption in the afternoons, during peak hours (commissioning of high power and medium power devices). Finally, we fall to very low consumption at night following the hours of severe crisis (lighting circuits and medium power devices).

II.2.7 Simulation of the evolution cycle of a workstation

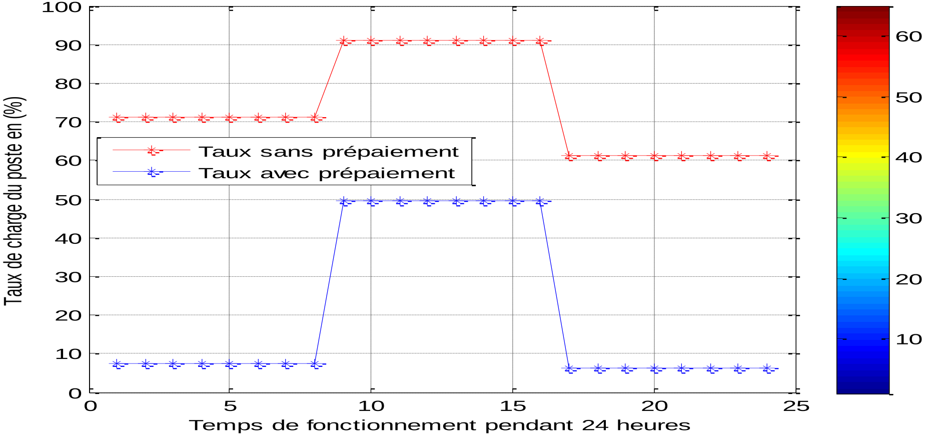


Fig II.5: Simulation of a workstation evolution cycle.

III. CONSUMPTION BASED MODELS

III.1 Energy needs of the zones

In developing countries, there are two types of users in rural areas; households and users in the service sector (petty trade, crafts, education, health centers, etc.). Farm households are the biggest consumers of energy overall.

III.2 Models based on the consumption of an area

These are the models which have as elementary simulation scale an electrical consumption of the form Pz. We'll talk work only on the time component of power consumption. We can write forecast models in the form.

$$\{P^{Z}(t_n + h)\} \sim (\{P^{Z}(t_i)\} i \epsilon 1 : n - 1, P_a, S, L, M_e, M_a) \quad (3.1)$$

III.3 Models using individual consumption

To access consumption by type of customer, many researchers use individual consumption data Pj. Using data from individual measurements is not always suitable, especially in certain countries where representativeness is not sufficient, or if the deployment is too recent to cover sufficiently long measurement periods.

So if the set K of customer categories is exhaustive, we can find the consumption of the zone from the consumption of each category:

$$P^Z = \sum_{k\epsilon K} \sum_{j\epsilon J_K{}^Z} (P^j) = \sum_{k\epsilon K} (P_K{}^Z) \quad (3.2)$$

III.4 Models using consumption by zone

We assume that demand by area is a sum of different proportions of profiles associated with different categories of customers. This type of model allowing such a generation of profiles is new to our knowledge in the literature. Formally, this model assumes that the electrical consumption of an area is:

$$\mathrm{P^Z} = \sum_{\mathrm{k\epsilon K}} \mathrm{P_k}^{\mathrm{Z}}\, \mathrm{P_k} + \epsilon^{\mathrm{Z}} \qquad (3.3)$$

III.5 Models based on consumption by use

One of the models of this type is that which breaks down the temperature-sensitive uses of those that are not temperature-sensitive from load curves for different zones. Formally, these models assume that:

$$\mathrm{P^Z} = \sum_{\mathrm{k\epsilon K}} \mathrm{P_k} \qquad (3.4)$$

III.6 Models based on consumption per customer

The models we have identified in this category use data from advanced meters to make short-term electricity consumption forecasts for individual customers, with the aim of estimating demand often in smart grid or micro grid contexts. grid.

These models use individual power consumption data by training on a statistical model and then compare and calibrate the model with the data over the predicted horizon.

$$\{\mathrm{P^j}(\mathrm{t_n} + \mathrm{h})\} \sim (\{\mathrm{P^j}(\mathrm{t_i})\}\mathrm{i\epsilon 1{:}n} - 1, \mathrm{T_a})(3.5)$$

III.7 Models based on consumption per device

These models are called in abbreviation “NILM” in English for Non-Intrusive Load Monitoring. This involves breaking down the power consumption of individual customers by usage using individual customer metrics.

training on a statistical model and then compare and calibrate the model with the data over the predicted horizon. These methods thus make it possible to estimate the presence or absence of devices and their condition at a customer's premises based on individual consumption measurements, and this estimate can be aided by information on the fleet of devices, socio-economic or meteorological. These models can better predict short-term individual consumption by knowing the state of the various charges. Formally, this type of model amounts to:

$$P_a \sim (P^j, S, Me) \qquad (3.6)$$

IV. Consumption modeling

Different models are approached, with the aim of reconstructing and predicting changes in electricity consumption. The accuracy of the parameters of the different models is evaluated on samples from an area. This periodic model has the following expression:

$$X_t = \delta_0 + \delta_1 x\, t + \sum_{j=1}^{n} \left[\beta_j X sin\left(\frac{2\pi jt}{12}\right) + \gamma_j X cos\left(\frac{2\pi jt}{12}\right)\right] + \varepsilon_t \qquad (4.1)$$

IV.1 Consumption of a household in the city of Kinshasa

In Kinshasa, in any house, for a basic use of household appliances, the power will be close to six kilowatts. This consumption will be that corresponding to the light, the refrigerator and the small household appliances of daily use, such as the dryer, the radio cassette or the vacuum cleaner.

On the other hand, for a house which has a dishwasher, a washing machine and a kitchen or an electric oven, the average power

will increase to ten kilowatts. If you use the kitchen and the electric oven at the same time, you will need at least fifteen kilowatts.

IV.1.1 Household model

The technical sheet makes it possible to take stock of the power of the household, that is to say all the powers of household appliances. This power is obtained by the following expression:

$$P_t = \sum_{i=1}^{n} P_{réc} \qquad (4.2)$$

$$P_t = P_{réc1} + P_{réc2} + P_{réc3} + \cdots + P_{récn} \quad (4.3)$$

IV.1.2 Models of daily consumption by device

We have although the consumption of electric energy, is the product of the power according to the time of use of the receiver. This consumption is expressed by the following relation:

$$C_S = P_{ch}\, x\, (t_1 \pm t_2) \qquad (4.4)$$

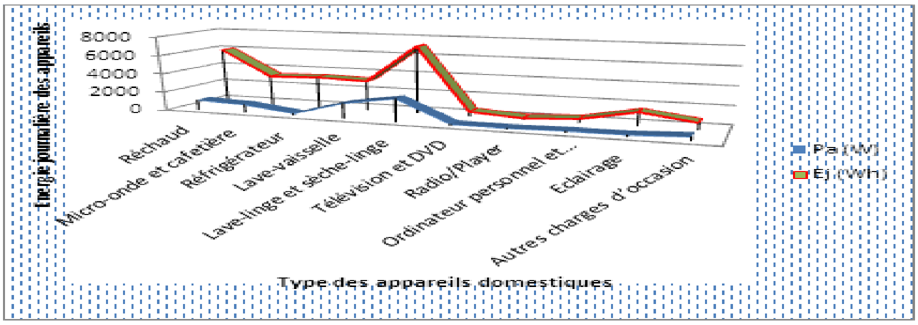


Fig IV.1: simulation of consumption per receiver.

IV.1.3 Long-field consumption models

The long-field power consumption of a device consists of determining its consumption per week, per month, per quarter until its annual consumption is obtained. This consumption is a function of the coefficient of the field of use, which takes into account the exact number of days that the device was actually used. This energy is determined by the following expression:

$$E_{LC} = E_j\, x\, k_{LC} x\, N_j \qquad (4.4)$$

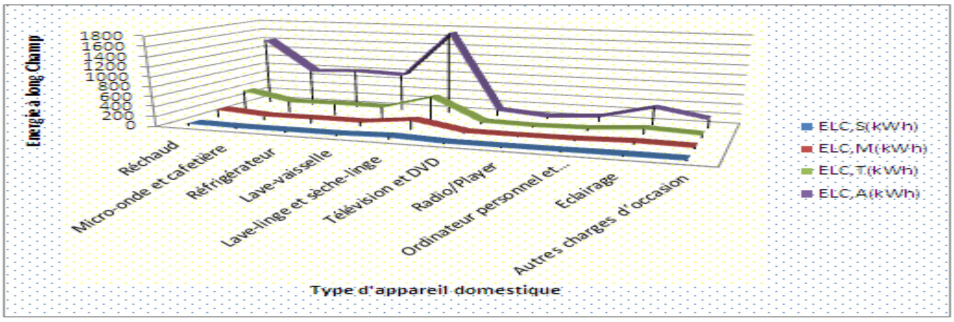


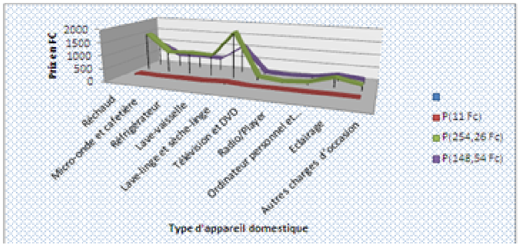
Fig IV.3: Long-term simulation by type of device.

IV.2 Prepayment of a device from the city of Kinshasa

The prepayment pricing policy has not yet been enacted in the Democratic Republic of Congo in general, and particularly for low-voltage subscribers in the city of Kinshasa. Several price indexes are charged in the prepayment of the city of Kinshasa since 2016 until these days the rates are recorded in Congolese Francs which have varied between 11 to 254.26.

IV.2.1 Daily prepayment of devices

It is important to know the daily cost of each appliance. For a financial simulation, in the absence of a pricing regulation, our calculations will be based on the three prices (11, 254.26 and 148.54) in Congolese Francs.



IV.2.3 Prepayment of the long-field device per month

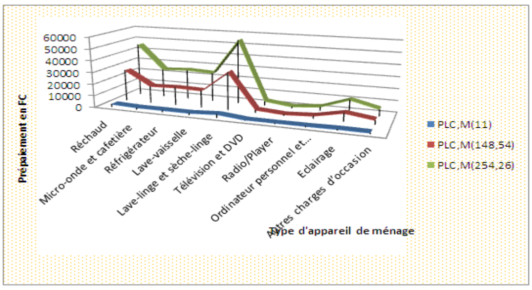


Fig IV.4: Long-field prepayment simulation by type of device

IV.2.5 Prepayment of the annual long-field device by quarter

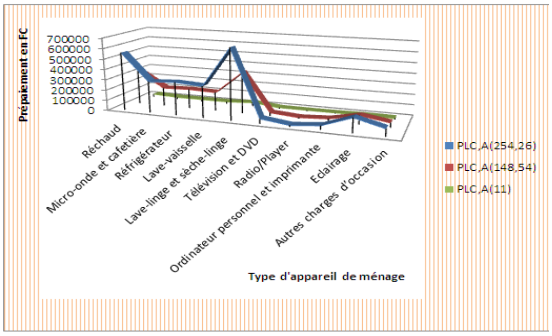


Fig IV.6: Long-field prepayment simulation by type of device.

IV.2.2 Prepayment of the long-field device per week

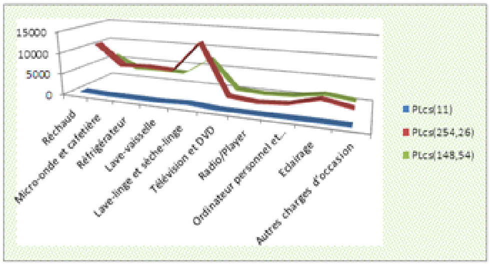


Fig IV.3: Long-field prepayment simulation by type of device.

IV.2.4 Prepayment of the long-field device by quarter

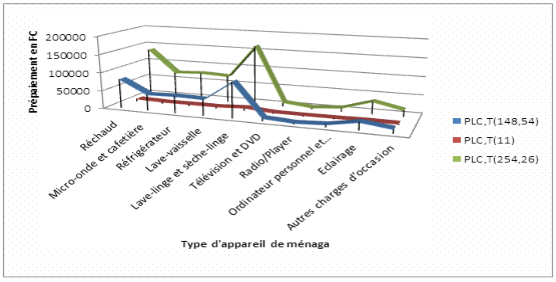


Fig IV.5: Long-field prepayment simulation by type of device.

IV 3 Payment simulation in Matlab

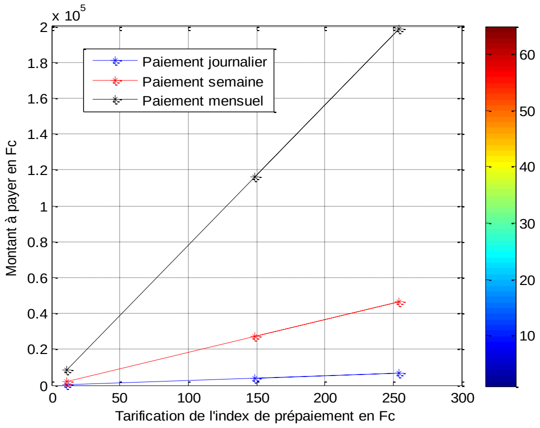


Fig IV.7: Simultaneous simulation of prepayment by type of device

The blue curve shows the evolution of prepayment payment for energy consumed with the tariff of 11 Congolese francs. While, the red curve shows the evolution of prepayment payment for the energy consumed with the tariff of 245.26 Congolese francs. Finally, the curve in black gives the appearance of the evolution of prepayment payment for energy consumed with the tariff of 148.54 Congolese francs

V. CONCLUSION

We have seen that this article consisted of determining consumption by use directly from the entrance to the installation. The identification method used for any electrical device that reflects the permanent operation of the electrical installation. We applied this method to the monthly and daily payment resulting from the simulation with Excel software and simulink under the Matlab environment.

This article presents the models of the calculations allowing to standardize the loads and as well as the chosen consumption. This last step will allow us to facilitate the phase of classification and grouping of expenses by household. The developed method is capable of detecting changes of state which eliminates the need for use. These changes of state can appear simultaneously or successively without any problem of interpretation.

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