

# Intelligent Power Theft Detection Model for Prepaid Energy Metering In Nigeria

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**Abstract** – The Nigerian Power Sector has been suffering from huge revenue loss due to power theft. In recent years, the Power Utility Company of Nigeria known as the Power Holding Company of Nigeria (PHCN) has deployed different metering technologies to battle this setback. Prepaid meters with prepaid card and smart card have been recently introduced in some locations in Benin City, Port Harcourt, Lagos state etc. Still the problem of “tampering and bypass” which are the major types of power theft have been left without solutions. In this paper, an Intelligent Power theft detection system (IPTDS) with instantaneous SMS alert is proposed. The set up contains an Intelligent Statistical Meter (ISM) placed at the transformer end or on Electric High Pole. It communicates with the various consumer meters linked with it through RF and GSM technologies. It monitors and continuously sums up the total energy consumption measurements from various consumers’ meters in a designated region; and sets it as a reference value. Whenever this reference value is exceeded, an unmetered (illegal) load or power theft is detected. An SMS alert is triggered and sent to the Utility Company for necessary action. The algorithm for this proposed power theft detection has been developed; and the entire idea has been modeled and simulated in MATLAB/SIMULINK environment. Results obtained are very satisfactory. When fully implemented by the PHCN, power theft will be greatly reduced and revenue collection will greatly increase.

**Keywords** – Power Theft, Intelligent Statistical Meter (ISM), Intelligent Prepaid Energy Meter (IPEM), SMS, Non Technical Losses (NTL).

## I. INTRODUCTION

The major problem plaguing the Nigerian Power Sector today is Power theft.. Power theft or Electricity theft is basically an illegal way of getting the energy for different uses, resulting in loss for utility companies. According to [1, 2] it can be in the form of fraud (meter tampering), stealing (illegal connections), billing irregularities, and unpaid bills. These illegal activities have led to huge revenue loss in Nigerian Power Sector [3].

Several research studies have been carried out to tackle this monster. Authors in [4] extensively studied Non Technical Loss (NTL) detection of electricity theft and abnormalities for large power consumers In TNB Malaysia where they raised the issue of dishonesty of the Electricity consumer being a problem faced by all power utilities and tried to find efficient measurements for detecting fraudulent. A novel anti-theft and detection method of street lamp power cables was also studied in [5] where a

novel anti-theft and detection method of street lamp power cables was presented by the authors.

In [6], the authors studied Nontechnical Loss Detection for Metered Customers in Power Utility Using Support Vector Machines where they presented a new approach towards nontechnical loss (NTL) detection in power utilities using an artificial intelligence based technique, support vector machine (SVM).

A model on theft control was proposed by authors in [7]. In this model they calculated Non –Technical Losses (NTL) in external control section, and if  $NTL > 5\%$ , legal customers are disconnected for some interval. Harmonic generator is operated in this time period, which destroys the electrical equipment of all the illegal consumers. Reconnect normal supply for genuine customers. However this model can be improved to stop functioning of the equipment of an illegal users, weather using smart meters or any other technique.

In [8] authors elaborated ways of communication, in how many ways data of smart meter to utility can be transmitted (2011). In [9] central server meter is placed, which is cost effective because a smart meter is placed at secondary side of transformer. It used matrix based approach in excel to show electricity theft case and normal case. Where as if large amount of data has to be managed than larger matrices will be required. Memory requirements will increase, time consumption to solve large matrices will increase.

Authors in [6, 10] have some mathematical modeling techniques which helps to detect and control electricity theft using some classifiers. like Support Vector Machine LINEAR (SVM-LINEAR), Support Vector Machine-Radial Basis Function (SVM-RBF), Artificial Neural Network- Multi Layer Perceptrons (ANN-MLP), Optimum Path Forest classifier (OPF) [8]. SVM is a regression based technique, in which dependent and independent variables are considered. It defines certain parameters to define a graph or compare it to the standard data or graph. In this method special kind of theft are recognized. If there occurs an abrupt change in load flow it notify that change and store that data as faulty one .

Lagrange function can also be the method to study load flow in electrical power system toward distribution. Lagrange basic function can be given as:

$$\mathcal{L} = \sum_{i=0}^N F_i + \lambda \left[ P_d - \sum_{i=0}^N P_{gi} \right] \quad (1)$$

$$\frac{d\mathcal{L}}{dP_{gt}} = \frac{dF_i}{dP_{gt}} - \lambda \quad (2)$$

Taking derivative of equation (1) to solve it for the generation cost of certain operating unit, we get equation (2). It can be the approach for finding technical and non-technical losses in one way as if we consider above equation including losses it will be in a form like:

$$L = \sum_{i=0}^N F_i + \lambda \left[ P_d + P_L - \sum_{i=0}^N P_{gt} \right] \quad (3)$$

Solving this equation we can find losses which are normally called as technical losses, that is losses on generation side. Using Lagrange for SVM we can change parameters in this formula for desired situation, further in this method we can get a matrix form, graph of standard form and collect data to identify theft. There is one other technique ANN-MLP which is based on modeling techniques, obeys some of non-linear statistical modeling or tree diagram. Other part of it is MLP which is a type of linear classifier and selects better output among outputs from its input. Ramos, C. C. O *et al.* proposed OPF based technique [8]. It is an approach in which better output is replaced for the previous value selected to reach to identify theft. It needs no parameters to be assumed. Its training phase operation is very fast, an overview is tested by [8] and showed that an OPF has a higher hit rate of theft and having more accuracy than SVM-LINEAR, SVM-RBF, and ANN-MLP [8].

In this work, an Intelligent Power Theft Detection Model is proposed. It's a network of three parts, namely: (i) the Intelligent Prepaid Energy Meter (IPEM) placed at the consumer's end (ii) Intelligent Power Theft Detection System (IPTDS) placed at the transformer end or electric high pole and (iii) Utility Control Server[11]. The IPTDS detects illegal connection when there is an unmetered energy consumption by a user. An SMS alert is triggered immediately to the utility company for necessary action. It basically uses the RF and GSM communication technologies.

## II. THEORETICAL BACKGROUND

Losses occur at all levels, from generation, through transmission and distribution, to the consumer and the meter. It is normally at the distribution level where the majority of avoidable losses occur. All electrical power distribution companies operate with some accepted degree of losses. This is no different from the scenario in Nigeria. Losses incurred in electrical power systems have two components, namely ( i ) Technical losses and (ii) Non-technical losses.

### 2.1 Technical Losses

Technical losses are naturally occurring losses (caused by actions internal to the power system) and consist mainly of power dissipation in electrical system components such as transmission lines, power transformers, measurement systems, etc. Technical losses are possible to compute and control, provided the power system in question consists of known quantities, viz., resistance, reactance, capacitance, voltage, current and power. These are routinely calculated by utility companies as a way to specify what components will be added to the

systems. Loads are not included in the losses because they are actually intended to receive as much energy as possible. Technical losses in power systems are caused by the physical properties of the components of power systems. Example,  $I^2R$  loss or copper loss – in the conductor cables, transformers, switches and generators.

The most obvious example is the power dissipated in transmission lines and transformers due to their internal impedance. Technical losses are easy to simulate and calculate; computation tools for calculating power flow, losses, and equipment status in power systems have been developed for some time.

The instantaneous power loss,  $P_{loss}(t)$  in a transmission line can be expressed as:

$$P_{loss}(t) = P_{source}(t) - P_{load}(t) \quad \dots\dots\dots 4$$

where  $P_{source}(t)$  is the instantaneous power that the source injects into the transmission line and

$P_{load}(t)$  is the instantaneous power consumed by the load at the other end of the transmission line. Thus

the energy loss,  $E_{loss}$ , is given by:

$$E_{loss} = \int_a^b P_{loss}(t) dt \quad \dots\dots 5$$

where  $a$  and  $b$  are respectively the starting point and ending point of the time interval being evaluated. It must be noted that a fairly accurate description of  $P_{loss}(t)$  as a function of time is always needed to make a reliable prediction of  $E_{loss}$ .

### 2.2 Non-Technical Losses (Commercial Losses)

These refer to losses that are independent of technical losses in the power system. Two common breakdowns that drastically increase losses before they are replaced and electricity theft. Losses incurred by equipment breakdown are quite rare. These include losses from equipment struck by lightning, equipment damaged by time and neglect. Most power companies do not allow equipment to breakdown in such a way and virtually all companies maintain some form of maintenance policies. Other probable causes of commercial losses are:

- Non-payment of bills by customers
- Errors in technical losses computation
- Errors in accounting and record keeping that distort technical information.
- Inaccurate or missing inventories of data on customers

The most prominent forms of commercial losses in Nigeria are electricity theft and non-payment of bills. Non-payment, as the name implies, refers to cases where customers refuse or are unable to pay for the electricity used. However, the other forms are not analyzed thoroughly in this project. Nontechnical losses are very difficult to quantify or detect and are more problematic than the other losses.

Non-technical losses can also be viewed as undetected load; customers that the utilities do not know exist. When an undetected load is attached to the system, the actual losses increase while the losses expected by the utilities remains the same. The increased losses will show on the utilities' accounts, and the costs will be passed to customers as transmission and distribution charges.

### III. DESIGN METHODOLOGY

The operation principle of the Intelligent Power Theft Detection System (IPTDS) is based on unmetered consumption detection method which involves installing a utility IPTDS with a tree of meters so that a meter closer to the root measures the power consumed by the loads below it. By placing an “ Intelligent Statistical Meter (ISM) ” at a node of the residential power grid and additional meters below it that measure the consumption of branches or specific loads in the tree below, the system performs a comparison between the Main ISM and the branch/load meters ISM. If the main ISM measurement is greater than the sum of the downstream meters measurements, it is a strong indication of an illegal load that consumes power. An SMS alert is automatically sent to PHCN for on site visit[12]. Figure 3.1 shows the structure of the Intelligent Power Theft Detection System (IPTDS).

The Intelligent power theft detection system (IPTDS) consists of the following:

- **Main Intelligent statistical Meter (ISM):** It sums up the overall energy consumption in the network at a particular time. It compares the result obtained with the total actual metered energy consumption in the network. An sms alert for on- site visit is triggered whenever there is a positive difference in value. This main ISM is recommended to be placed at the transformer.

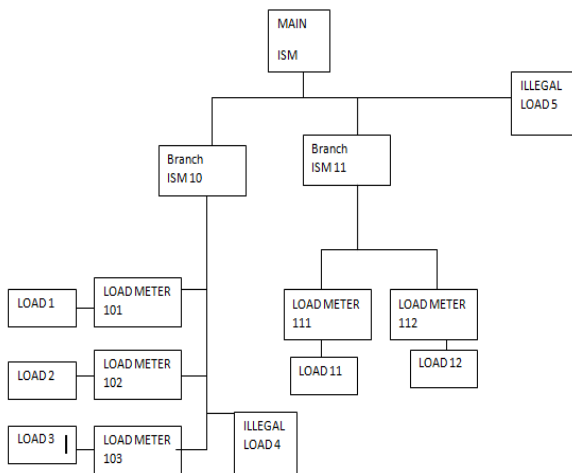


Fig. 1. IPDTS based on unmetered consumption detection method

- **Branch ISM:** It's function is similar to that of the main ISM except that it's a concentrator for smaller coverage region. It is recommended to be placed on a high pole. See Fig.2
- **Load Meter:** It's an Intelligent Prepaid Energy Meter (iPEM) which measures the energy consumed by the load connected to it. This measurement is called the metered energy.
- **Load:** This is the true load (metered load) connected to the Load meter. Load 1, load 2, load 3, load 11 and load 12 as seen in Fig 1.

- **Illegal Load:** This is the unmetered load. This load enjoys energy consumption from the power utility through bypass (power theft). From fig.1 , Load 4 and load 5 are illegal loads. The illegal connection or bypass are done before the power utility meters.

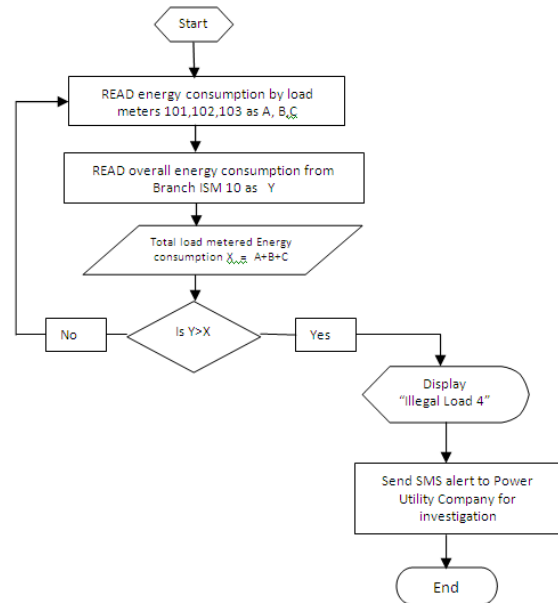


Fig.2. Mode of Operation Flow Chart of Branch ISM 10 in the IPT

#### 3.1 Hardware Architecture of the ISM in the IPDTS Model

The IPDTS contains an Intelligent Statistical Meter(ISM) which consists of the following modules: a micro-controller unit, a Liquid Crystal Display (LCD), an Electrically Erasable Programmable Read Only Memory (EEPROM), Real Time Clock (RTC), an Energy Measuring Module (EMM), Tamper detection unit, Latching Relay (LR) and a GSM modem as shown in Fig .3.

The ADE7756 IC is used for energy measurement. It is interfaced to a microcontroller through a serial interface (SPI). The SPI port allows the user to calibrate various components of the meter, including gain, offset, and phase errors. The purpose of the microcontroller is to send display data to the LCD and control the various functions of the meter. An EEPROM is used to store various calibration parameters of the meter and store the meter's data during a power-down. The GSM module provides the wireless communication and SMS-based facility for the design. Power connection/disconnection to the load is implemented using a Relay.

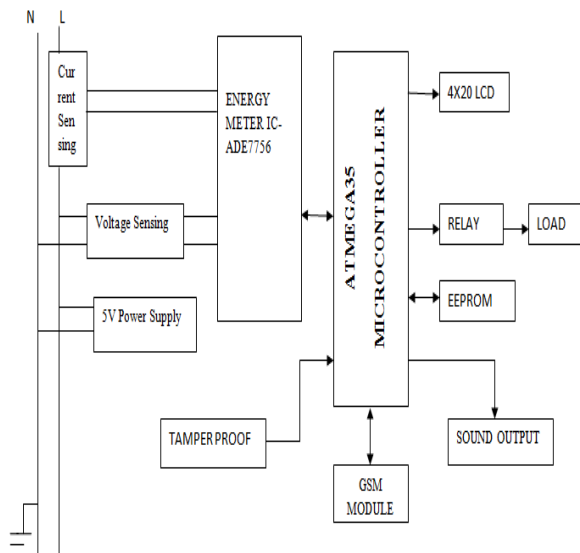


Fig.3. Block diagram of the ISM in the IPDTS Model

The relay receives instructions from the microcontroller through its input signal pins. System working current time data is recorded by the RTC. The power supply unit provides the operational voltage of 5volts for the ADE7756 IC, Microcontroller and the LCD .The entire meter is calibrated through an external calibration routine by a PC through an external SPI interface.

### 3.2 Mathematical Modeling of the theft case algorithm in the ISM

The power,  $P$ , in an electrical system is given as:

$$P = IV \cos\theta \quad \dots\dots\dots 6$$

and the instantaneous current is also given as:

$$I(t) = I_m \sin(\omega t \pm \phi) \quad \dots\dots\dots 7$$

Let  $I_L(t) = I_{Lm} \sin(\omega t \pm \phi)$  be the current sensed by the load meters and  $I_B(t) = I_{Bm} \sin(\omega t \pm \phi)$  be the current sensed by the Branch ISM. Assuming that the internal circuitry of the meters are purely resistive, then the corresponding voltage relations for  $V_L(t) = V_{Lm} \sin(\omega t \pm \phi)$  and  $V_B(t) = V_{Bm} \sin(\omega t \pm \phi)$  respectively and these will form as the input into the comparator as seen in Fig.4. Therefore, the output voltage,  $V_o$ , from the comparator is given as:

$V_o = A(V_B - V_L)$  Thus,  
 $V_o = A\{[V_{Bm} \sin(\omega t \pm \phi)] - [V_{Lm} \sin(\omega t \pm \phi)]\} \dots\dots\dots 8$

Note that four scenarios can be derived from Equation 3. These are:  
 $V_o = A\{[V_{Bm} \sin(\omega t + \phi)] - [V_{Lm} \sin(\omega t + \phi)]\} \dots\dots\dots 9$   
 $V_o = A\{[V_{Bm} \sin(\omega t + \phi)] - [V_{Lm} \sin(\omega t - \phi)]\} \dots\dots\dots 10$

$$V_o = A\{[V_{Bm} \sin(\omega t - \phi)] - [V_{Lm} \sin(\omega t + \phi)]\} \dots\dots\dots 11$$

$$V_o = A\{[V_{Bm} \sin(\omega t - \phi)] - [V_{Lm} \sin(\omega t - \phi)]\} = A(V_{Bm} - V_{Lm}) \sin(\omega t - \phi) \dots\dots\dots 12$$

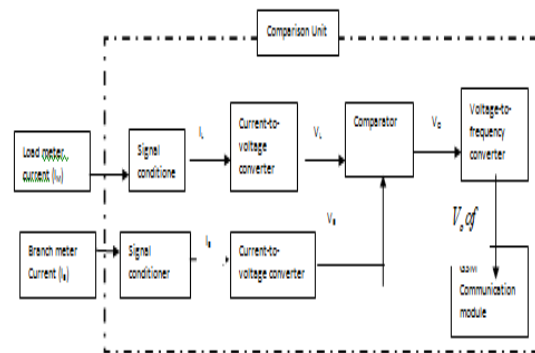


Fig.4. Block diagram of the comparison unit in the ISM

Either Equations 9 or 12 could be used for the comparison because for a purely resistive circuit, the phase will remain the same at both the input and the output. Consequently, should the amplitude difference,  $V_{Bm} - V_{Lm}$ , exceeds zero, then a theft case will have occurred and it is fed into a voltage-to-frequency converter to generate a periodic output waveform having a frequency proportional to the magnitude of an applied DC input voltage. For any discrepancies recorded, the current in the system will vary.

### 3.3 Simulation Models using Matlab/Simulink

Simulink is a graphical extension to MATLAB for the modeling and simulation of systems. Simulink is integrated with MATLAB and data can be easily transferred between the programs[13]. The Simulink block design for both IPTDS and its internal architecture are shown in Fig.5 and Fig. 6 respectively. Tables 1, 2 and Fig.7, 8 show the simulated results.

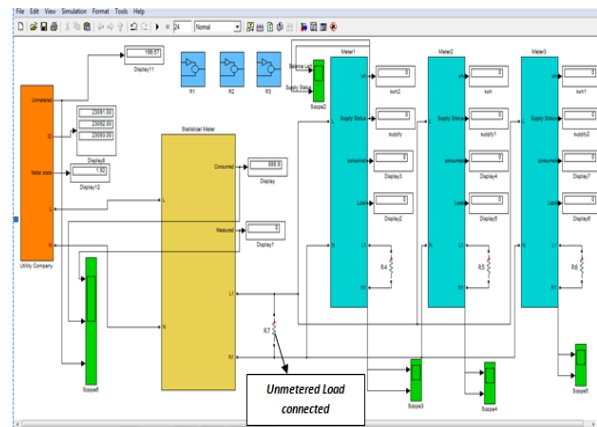


Fig.5. IPDTS model for detecting "unmetered" load



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