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A METHODOLOGY FOR THE DESIGN OF AN ELECTRICITY THEFT MONITORING SYSTEM

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ABSTRACT

Utility companies in Ghana estimate that electricity theft costs them over a billion US dollars in annual revenues. The purpose of this work is to provide an algorithm for the design of electricity theft monitoring system which allows violators to be detected at a remote location. It begins with the analysis of losses in electrical power systems. The bulk of these losses are caused by electricity theft, rather than other possibilities such as poor maintenance and calculation and accounting mistakes, though some power systems may suffer from both. Other aspects discussed include the various forms of theft practices, methodology for detection of theft, generating the theft case algorithm using the backtracking algorithm method and communicating these data from the consumer premises to the substation using the existing power lines. Appropriate conclusions and recommendations were given from the information gathered.

Keywords: *Electricity Theft, Monitoring System, Algorithm, Power Line Communication*

1. INTRODUCTION

According to Smith [1], electricity theft can be in the form of fraud (meter tampering), stealing (illegal connections), billing irregularities, and unpaid bills. The evidence of the extent of electricity theft in a sample of 102 countries between 1980 and 2000 shows that theft is increasing in most regions of the world. The financial impacts of theft are reduced income from the sale of electricity and the necessity to charge more to consumers.

Electricity theft is closely related to governance indicators where higher levels are recorded in countries without effective accountability, political instability, low government effectiveness and high levels of corruption.

Merely generating more power is not enough to meet present day requirements. Power consumption and losses have to be closely monitored so that the generated power is utilised in an efficient manner. This illegal electricity usage may indirectly affect the economic status of a country. Also the planning of national energy may be difficult in case of unrecorded energy usage.

This paper discusses the design of an algorithm to monitor distribution systems for theft.

2. OVERVIEW OF THE ELECTRICITY SECTOR IN GHANA

The Volta River Authority (VRA) and Ghana Grid Company (GRIDCo) are responsible for generation and transmission of electricity in Ghana respectively. Also, the Electricity Company of Ghana (ECG) is responsible for the distribution of electricity to consumers in the southern and middle belts of Ghana, viz., Ashanti, Central, Greater Accra, Eastern, Western, parts of Brong Ahafo and Volta Regions of Ghana, whereas the Northern Electrification Department (NED) is responsible for the distribution of electricity to consumers in the northern belt of Ghana, viz., parts of Brong Ahafo, Northern, Upper East and Upper West Regions of Ghana. A sketch of the electric power generation, transmission and distribution network in Ghana is as shown in Figure 1.

Consumers on the distribution system are categorized as industrial, commercial and residential. Industrial consumers' use of energy is fairly constant, both over the day and over seasons.

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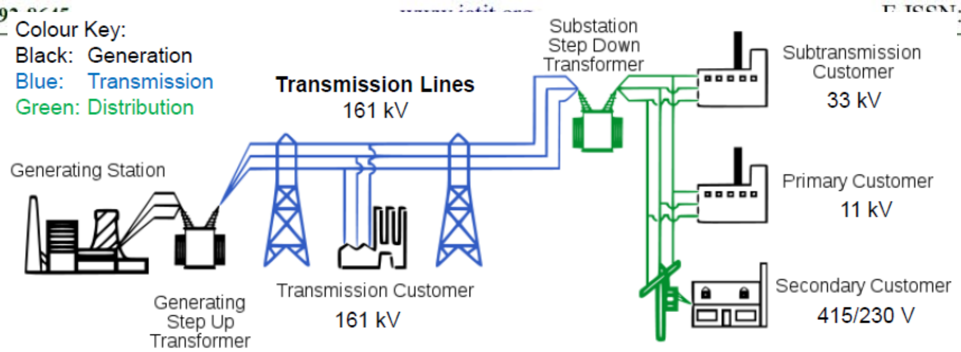

Figure 1 - Electric Power Generation, Transmission and Distribution Network in Ghana

However, that of commercial users is less constant and varies over the day and seasons. Residential and commercial uses are more variable, sometimes changing rapidly over the day in response to occupant needs and appliance use.

Amoah [2] states that, as of December 2003, the entire distribution system of Ghana comprised of 8,000 km of sub-transmission lines, 30,000 km of distribution networks with 22 bulk supply points and 1,800 MVA of installed transformer capacity. Power distribution systems provide power to customers through power lines.

3. ANALYSIS OF LOSSES IN POWER SYSTEMS

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 Ghana. Losses incurred in electrical power systems have two components:

- Technical losses and
- Non-technical losses (Commercial losses)

3.1 Technical Losses

Technical losses will always arise as the physics of electricity transport means that, no power system can be perfect in its delivery of energy to the end customer. 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:

$$P_{loss}(t) = P_{source}(t) - P_{load}(t) \qquad 1$$

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, W_{loss}, is given by:

$$W_{loss} = \int_a^b P_{loss}(t)dt \qquad 2$$

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 W_{loss}.

3.2 Non-Technical Losses (Commercial Losses)

These refer to losses that are independent of technical losses in the power system. Two common

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examples of sources of such losses are component 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 Ghana 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. Non-technical 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.

Research has shown that, transmission and distribution costs in Ghana are calculated as part of the customers' bills, while in other countries, customers are usually charged a single flat energy rate that includes all services. This means that, the transmission and distribution losses that increased due to commercial losses would be charged either to the existing customer whose power lines are illegally tapped, or the utility, depending on the method of theft.

Both ECG and NED losses range from 24 to 30 percent of power generated, collection rates range from 75 to 85 percent of billing and arrears from government agencies significantly weaken balance sheets [3]. In recent years, ECG has undertaken several measures to reduce losses. Figure 2 shows the total distribution losses of ECG from 1985 to 2003. From the figure, it is observed that losses were relatively low between 1993 and 1996 but increased thereafter.

3.3 Electricity Theft as a Major Component of Commercial Losses

Commercial losses arising through electricity

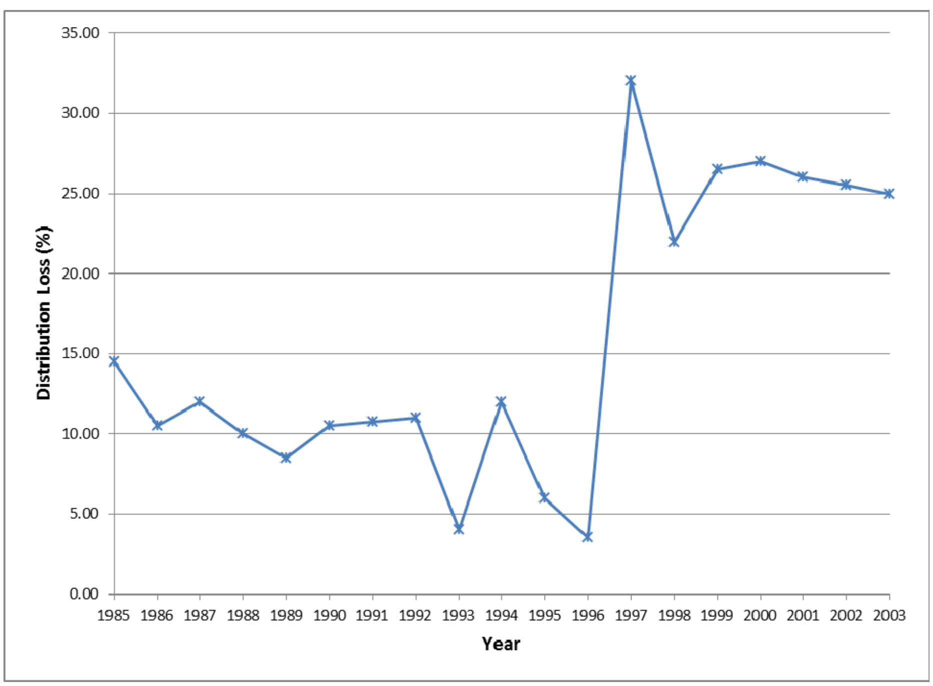

Figure 2 - Total Distribution Losses of ECG, 1985-2003

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theft and other customer malfeasances is a universal problem in the electricity supply industry. Such loss may occur by a number of means, such as meter tampering, illegal connections, billing irregularities, and unpaid bills. The associated identification, detection, and prediction procedures are important for many utilities, particularly those in developing countries like Ghana. Currently, most solutions are ad-hoc and can only be implemented after a long period of detection and observation.

The use of electricity is considered illegal if:

- Electrical energy is consumed without legal agreement between the providers and consumers.
- The consumer does not comply with the agreement clauses for the consumed energy such as entirely or partially not measuring the energy consumed and intentionally enforcing an error to the measuring device (Watt-hour Energy Meter).

In Ghana, meter inspection is the main method of commercial losses detection because the majority of electricity theft cases involve meter tampering or meter destruction. The principles of operation for watt-hour meters essentially have not changed since the 1880s and the 1890s, when the watt-hour meter was invented. But the way of construction keeps on changing.

In some areas in Ghana, the loads are not metered or are metered communally rendering any loss calculations (technical or not) for that area useless. The majority of electricity theft cases involves meter tampering or meter destruction and often after one has been disconnected for non-payment of bill.

4. METHODOLOGY FOR DETECTION

The method includes receiving meter data of the measured power consumed by a customer, receiving delivered power data that includes data of the power delivered to the customer, determining a difference between the meter data and the delivered power data, determining that the difference between the meter data and the delivered power data is greater than a predetermined amount, and indicating a discrepancy if the difference between the meter data and the delivered power data is greater than a predetermined amount.

In addition, the method may include determining that a discrepancy varies over time by a predetermined amount and providing a discrepancy notification through power lines. The block diagram in Figure 3 shows the basic components of the system mentioned.

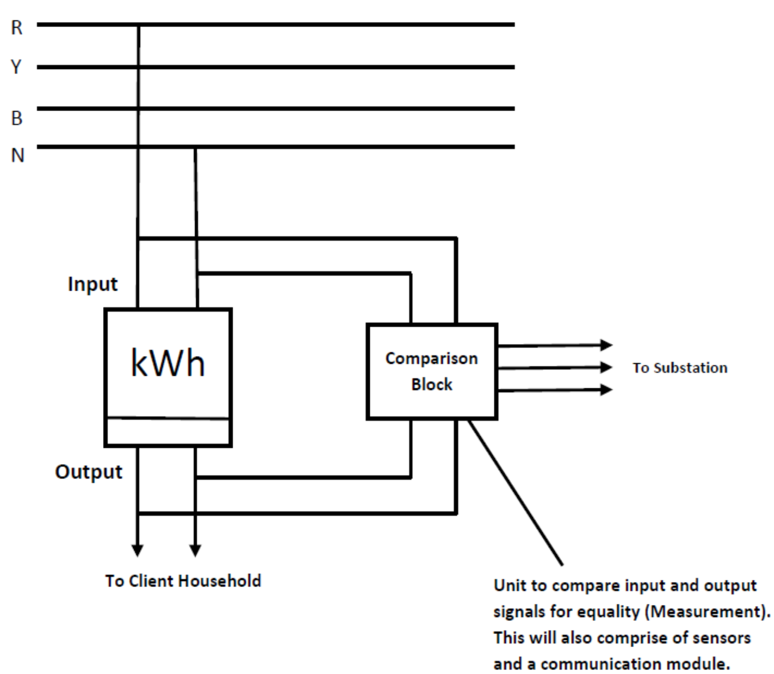

Figure 3 - Block Diagram showing the Methodology for Detection

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4.1 Mathematical Modeling of the Theft Case Algorithm

In this paper, the backtracking algorithm was used for the analysis. Backtracking is a refinement of the brute force approach, which systematically searches for a solution to a problem among all available options. Backtracking algorithms are distinguished by the way in which the space of possible solutions is explored. Sometimes a backtracking algorithm can detect that an exhaustive search is unnecessary and, therefore, it performs much better. Figure 4 will be used for generating the necessary algorithms.

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

Note that four scenarios can be derived from Equation 6. These are:

$$V_o = A\{[V_{2m}\sin(\omega t+\phi)]-[V_{1m}\sin(\omega t+\phi)]\} \\ = A(V_{2m}-V_{1m})\sin(\omega t+\phi) \quad 7$$

$$V_o = A\{[V_{2m}\sin(\omega t+\phi)]-[V_{1m}\sin(\omega t-\phi)]\} \quad 8$$

$$V_o = A\{[V_{2m}\sin(\omega t-\phi)]-[V_{1m}\sin(\omega t+\phi)]\} \quad 9$$

$$V_o = A\{[V_{2m}\sin(\omega t-\phi)]-[V_{1m}\sin(\omega t-\phi)]\} \\ = A(V_{2m}-V_{1m})\sin(\omega t-\phi) \quad 10$$

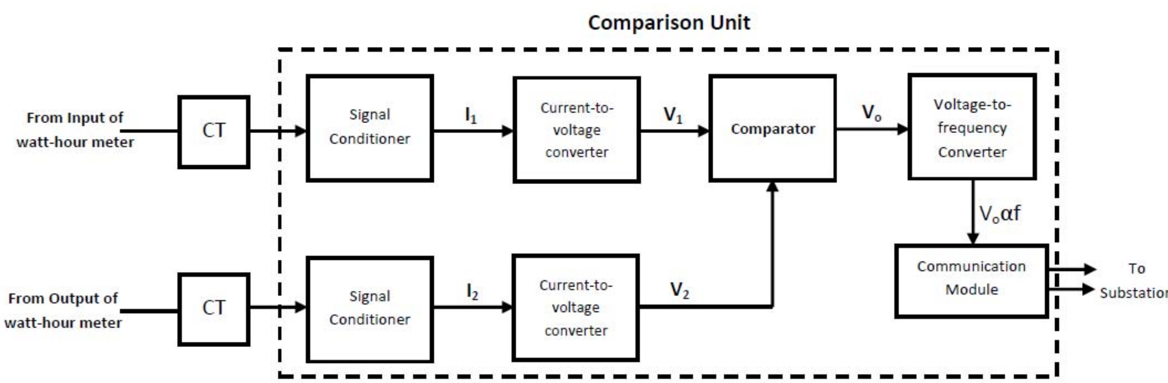

Figure 4 - Block Diagram of the Comparison Unit

$$P = IV\cos\theta \quad 3$$

and the instantaneous current is also given as:

$$I(t) = I_m \sin(\omega t \pm \phi) \quad 4$$

Let $I_1(t) = I_{1m}\sin(\omega t \pm \phi)$ be the input current to the meter and $I_2(t) = I_{2m}\sin(\omega t \pm \phi)$ be the output current to the meter. Assuming that the internal circuitry of the meter is purely resistive, then the corresponding input and output voltage relations are $V_1(t) = V_{1m}\sin(\omega t \pm \phi)$ and $V_2(t) = V_{2m}\sin(\omega t \pm \phi)$ respectively and these will form as the input signals for the comparator. Therefore the output voltage, V_o, from the comparator is given as:

$$V_o = A(V_2 - V_1) \quad 5$$

Thus,

$$V_o = A\{[V_{2m}\sin(\omega t\pm\phi)]-[V_{1m}\sin(\omega t\pm\phi)]\} \quad 6$$

Either Equations 7 or 10 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, $V_{2m}-V_{1m}$, exceeds a predetermined value, 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. Notably, an on-going theft case will lead to an increase in current. Figure 5 provides flowchart of how the comparison block in Figure 3 will operate.

When the mains is switched on, input and output signals of the watt-hour meter is compared to check for any discrepancies. When there is no discrepancy recorded, a green LED at the substation will be ON till a discrepancy occurs. With a discrepancy

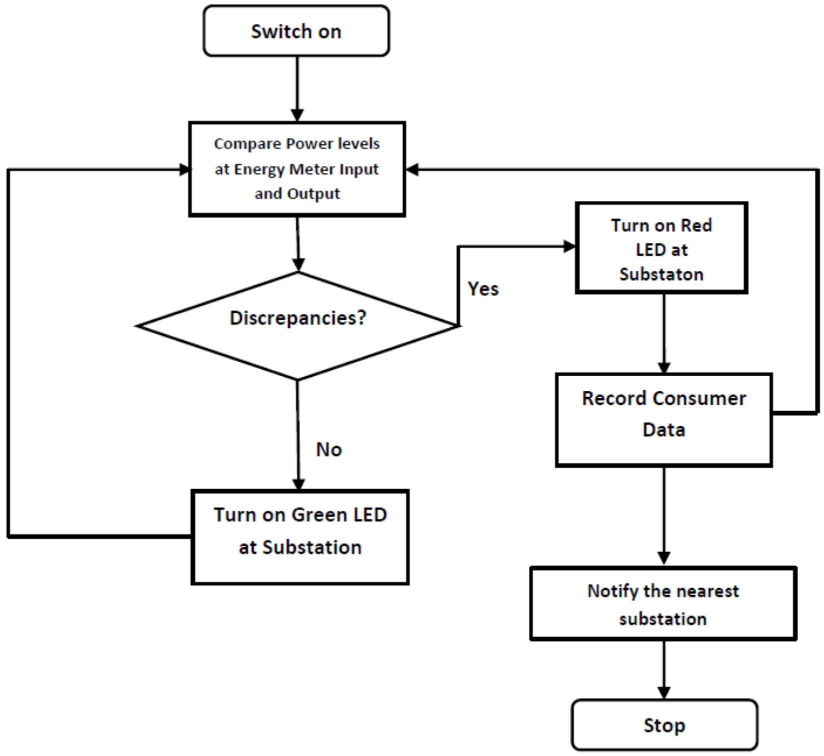

Figure 5 - Flow Chart of the Comparison Block

recorded, a red LED at the substation turns ON to notify the operator.

After notifying the operator that a discrepancy has occurred, the consumer data will also be recorded. The data will include the meter number, the time the problem started and the approximate location. When all the data has been taken, the nearest substation is notified and the operation is stopped or the mains turned OFF. All the sensor devices in the comparison unit will be located along the Low Voltage power lines and along the Medium Voltage power lines since they are the main lines where theft can take place.

5. CONCLUSIONS

Electricity theft, a common form of commercial losses, involves tampering with meters to distort the billing information or direct connections to the power system. Commercial losses are nearly impossible to measure using traditional power system analysis tools. This is due to the lack of information on both commercial and the legitimate loads in the system, which translates to insufficient inputs for any meaningful loss calculations. Despite the best efforts by utilities, the current results of commercial losses measurements are often inaccurate at best, because the figures rely heavily on the records of detected cases, rather than by actual measurement of the electrical power system. Certainly utilities have some control over the magnitude of commercial losses; but even with their best efforts, some commercial losses will still continue. An algorithm for the design of electricity theft monitoring system has been generated using the backtracking algorithm type.

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