Design and Construction of a Smart Energy Theft Detector on Distribution Lines

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Abstract: This work presents the design and construction of a smart energy theft detector on distribution lines. The escalating challenge of power theft within distribution lines necessitates innovative solutions to safeguard the integrity of power distribution networks. Atmega328-P, Arduino-uno Micro-processor was interphase with Bluetooth module to detect energy theft. Proteus professional software was deployed to determine the functionality of the smart energy theft detector. The work was tested and the result obtained showed a stand-alone system capable of detecting energy theft on different phases of the distribution network. The information sent to the utility operator's liquid crystal display (LCD) indicates theft detected on either red, blue or yellow phase.

Key words: Theft detector, Micro-Processor, Distribution network, Bluetooth module

I. Introduction

The increasing problem of energy theft on distribution lines has become a major concern for utilities and regulatory bodies alike. With the increased demand for electricity and the robust nature of the distribution network, energy theft prevention poses a great challenge to the sectors in charge. Over the years, energy theft has been revealed in several forms; ranging from unauthorized connections to meter tampering.

In Nigeria, due to the deficiencies in the metering system and the lack of transparency and accountability in billing customers of electricity in public utilities, customers take advantage to steal electricity to avoid paying the realistic tariff. Electricity theft causes a very high negative impact on the financial status of power distribution and utility companies, which puts pressure on future investment in the power sector. The ripple effect is that the losses incurred due to the theft are passed as the cost to the paying consumers in either poor quality service or higher tariff. The need for an effective and efficient power theft detection system has never been more evident.

Our work proposes a generalized smart system that detects energy theft by comparing the recorded values of current at the utility service intake to the recorded value of current at the energy meter intake. The result of the compared values is stored on the database server, which is accessible in real-time.

Energy theft, which for the purpose of this study can also be called "Electricity theft", refers to the act of consuming energy from a utility company without the said company's authorization [1].

The phenomenon of energy theft is usually prevalent in the distribution system of the power network; and on this basis, Shokoya and Raji [2] defines energy theft as the losses resulting in a positive disparity between energy fed to a distribution system and energy billed.

Energy theft is also the main cause of non-technical losses in a power network [2]. That is to say, losses as a result of external actions to the electrical power system.

The introduction of electricity meters by utility companies represented the first attempt to curb energy theft in the distribution sector. In Nigeria as a case study, the first categories of meters were the electromechanical types which utilized a spinning disc to record energy consumption. The electromechanical meters were mostly postpaid in nature; meaning that energy consumed was read by utility officials and then estimated bills distributed to the consumers. Another prevalent feature of these first-generation meters was that there was no accurate record of metered customers. These meters were used before the year 2005 [3] when the new power sector reform act, ushered in the now defunct "Power Holding Company of Nigeria" (PHCN). The PHCN introduced electronic meters in the country which were prepaid in nature and helped eliminate estimated billing. In later years, i.e. from 2015, smart meters began to be phased in gradually into the electricity industry; and since then, more metering technologies have been developed by

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independent and government sponsored researchers with a notable example being a metering system capable of being used as prepaid or postpaid while being fitted with a low-cost SMS two-way communication providing information exchange between consumer and utility company [4]

Before the advent of the smart systems there have been certain methods of energy theft detection such as manual meter readings and visual inspection. One method of energy theft detection and in extension, combating the ugly menace was proposed by Disha et Al [5] who suggested employing machine learning algorithms such as "extreme gradient boosting" (XG Boost) and optical character recognition (OCR) to detect cases of energy theft in electricity distribution system. The data used for this model is obtained from art meters. This data is then preprocessed i.e. transforming from raw data to an understandable format. According to them, the preprocessing stage includes data cleaning, data integration, data reduction, and data transformation. The next step includes feature selection i.e. choosing the essential variables that enables the correct prediction Viz current, voltage, and power consumption. The final stage of their research involved training the model using the machine learning algorithms. The main purpose of this is to create multiple models based on the obtained dataset and then combining the models to obtain an accurate result. The resulting model is then used to detect fraudulent energy used.

Some researchers turned to mathematics in their search for a means to curb energy theft. This is the basis for the research work of A.I. Abdulateef et Al [1] who proposed a method of energy theft detecting using a linear prediction technique. (Autoregressive method). This method involved a prediction of the future power consumption of a customer. Abdulateef et Al based their technique on the fact that the output of a linear system is a function of the input and the past outputs. They were of the opinion that if the future power consumption of a customer was predicted using their linear prediction model, the value could be a benchmark used to compare with the actual power consumed by that customer, and if the disparity between the two values were too great, then the customer is suspected of energy theft. Another innovation was achieved by Dike et Al [6] this involved the development of a GSM based prepaid meter system. This system helped in the remote monitoring of meter reading and sending an SMS whenever there were abnormal readings in the consumer electricity meter. It also provided a means of automatic disconnection of the defaulting phase when the recharge is low and connection when the recharge is high. The major components employed in this research was a GSM Bluetooth module for exchange of information, a microcontroller for comparison, an EEPROM (Electrically Erasable Programmable Rom) an energy meter and an Arduino based relay for switching on/off supply.

In a related research, S.T. Abel et al [7], proposed a distribution-customer system based on an AC-AC converter known as indirect Matrix converter. In this method, at the distribution end, the frequency of power is converted to 10Hz and at the consumer's end, the frequency is converted back to 50Hz. This discourages illegal tapping of energy as the 10Hz supply flowing along the lines is unfit to use. Also, a detection system proposed by D.S. Bhangari et Al [8] involved monitoring the data obtained from a current transformer at the electric pole service unit and comparing with the data collected from a similar current transformer at the consumer unit. If there is a deviation between the two values, the system automatically trips the load and sends a GSM message to the distribution centre. They employed an Arduino microcontroller as the decision maker hence providing a solution to the energy theft detection and mitigation. A similar technique was adopted by J.C. Mababa [9], the difference being that while [8] involved the use of current transformers, Mababa used current sensors to obtain his needed data.

Another research worth mentioning is a proposed detection technique by K.Udofia et Al [10] involving the comparison of the pole node voltages at each service pole with reference to connected consumer nodes.

Attempts to find solutions to energy theft has also extended to the Artificial intelligence domain, where deep neural networks are trained to detect electricity theft [11]. It is important to note that this technique is mostly applicable to smart grids. G.P. Dimf et Al employed a similar technique [12] in energy theft detection using Modified Deep Artificial Neural Network. The researchers in [13], [14], and [15] also utilized artificial intelligence tools to help solve energy theft problems.

II. Materials

In the construction of the smart energy theft detector, certain materials were used to achieve the model. Among them are;

i. Atmega328-P Microcontroller. ii. Liquid Crystal Display (LCD).
ii. Arduino Uno. iv. Electric Energy Meters. v. Current Sensors
iii. Voltage Sensors. Vii. Wi-Fi Module. viii. Connecting Wires
iv. Lamp holder. x. Energy Bulb. xi. 13A Sockets. xii. Patress Boxes
v. Adaptable Box. xiv. Relays. Xv. Push Button

2.1 Block Diagram Model

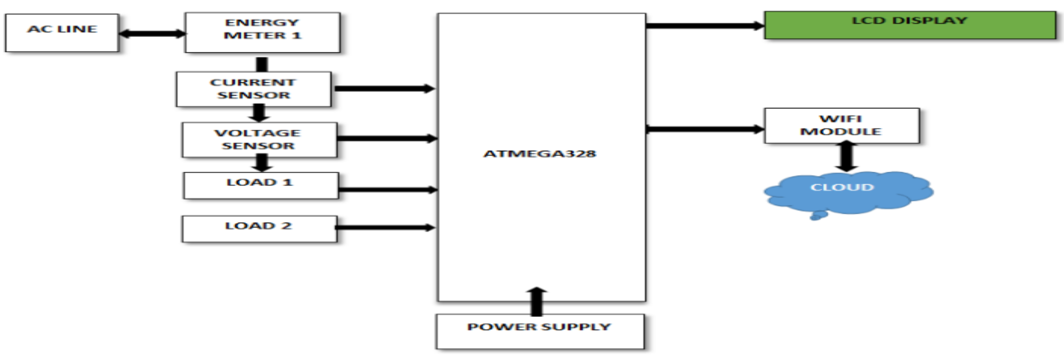

Figure 1: Block diagram model of the smart energy theft detector

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In figure 1 above, it is shown that the AC power supply line is affixed to the energy meters while the current sensors and voltage sensors are each attached to the lines between the energy meters and the loads. All these are then interfaced with the ATMEGA328-P microcontroller. Each sensor and the energy meters are treated as a separate node. A single node represents an individual point of power supply which may be an individual unit of home or the point where theft occurs. The current sensors start sensing power usage in the nodes whenever a load is operational. The various readings noted by the sensors in the presence of the operational loads are then passed on to the microcontroller, which gathers the information regarding power consumption in real-time. The gathered information is then processed in user-understandable formats and they are displayed up on the LCD screen after which the microcontroller checks for anomalies in the power consumption and the alert for power theft is given.

Information processed in the microcontroller is sent to the cloud, via the WI-FI module which is interfaced with a backend cloud storage space where the received data is maintained. The maintained data can be manipulated in a lot of ways which enables the utility providers to remotely manage and control the power flow from the electricity grids.

III. Method

The methods applied to achieve this system is design and simulation of the system. The design and simulation were done using a simulation software known as *proteus professional.* Proteus is a software tool for simulating electronic circuits and embedded systems. It allows users to design and test virtual prototypes of electronic circuits and devices.

3.1 Circuit Model Design

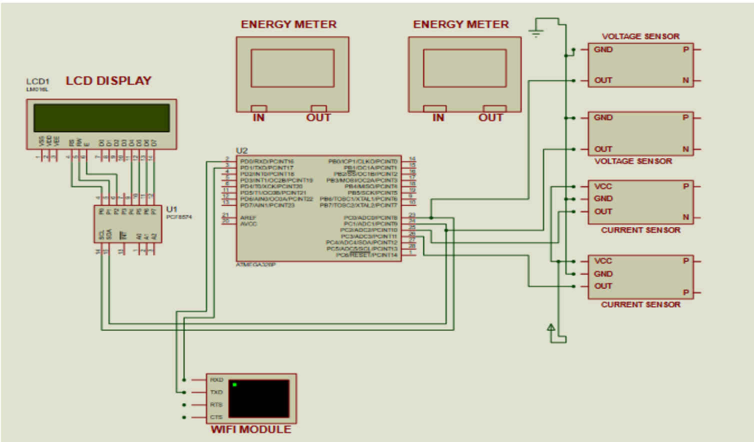

Figure 2: Circuit design of the energy theft detector

The diagram above shows the interconnection of the major components of the system. It depicts the circuit diagram representation of the components. Here, the microcontroller is used in conjunction with the energy meters, the LCD and the sensors.

3.2 Programming

The *css compiler* was used to achieve this. The Arduino IDE is used to boot load in the Atmega328-p microcontroller, this is done by keeping up the target microcontroller placed in the breadboard and the instructions are provided from the actual Arduino UNO board that is being connected with the PC via a USB port of the system. Once the required code along with the functionalities of the microcontroller are entered and debugged in the IDE then these are compiled it is burned onto the microcontroller.

Figure 3: The Proteus Software Interface

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IV. Data Analysis and Results

4.1 Power Consumption Analysis

In the analysis of the power consumed, the power consumed under normal conditions as well as under fault conditions were analyzed. Table 1 shows readings for the power consumed by the legal building. While figure 1 shows the graph of power consumed by the legal building.'

Table 1: Table of power consumed for legal building.

	LEGAL	
	CURRENT(A)	POWER(W)
PHONE	0.88	193.21
LAPTOP	0.1	219.04
PRESSING IRON	21.9	4816.94
ELECTRIC KETTLE	18.84	4143.96
ELECTRIC STOVE	16.37	3601.03

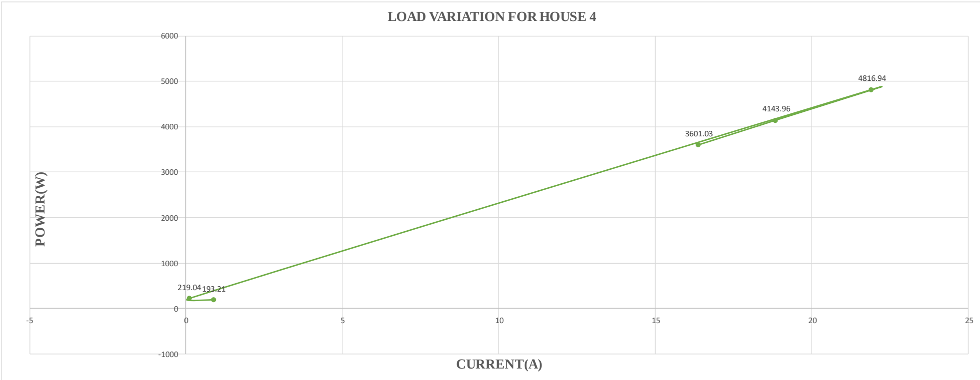


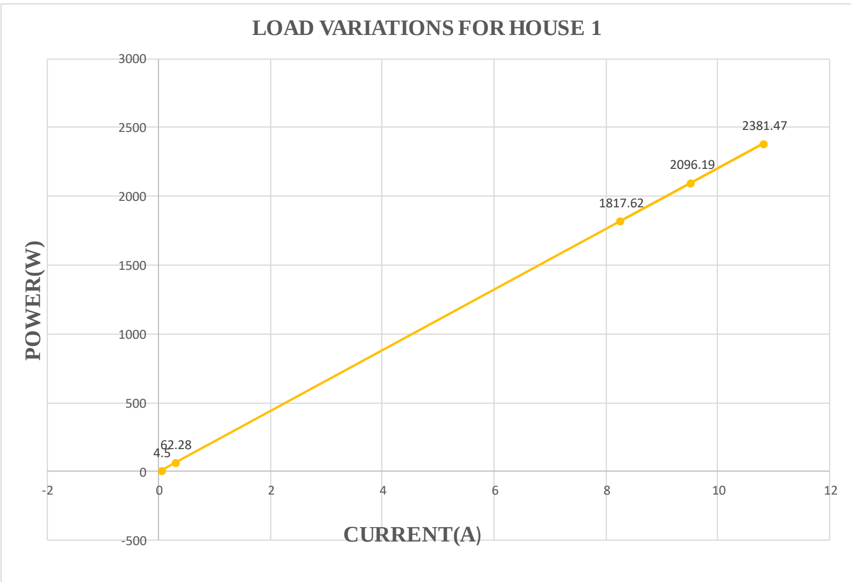
Figure 1: Graphical representation of the result obtained

From the data and the graph above, it was observed that power consumed by the appliances did not exceed or go below the preset values used in the Proteus design suite 8.10 simulation.

Below is the table of values and graph for the illegally connected loads.

Table 2: Table of power consumed for the illegal buildings

	HOUSE 2		HOUSE 1		HOUSE 3	
	CURRENT(A)	POWER(W)	CURRENT(A)	POWER(W)	CURRENT(A)	POWER(W)
PHONE	0.04	8.49	0.05	4.5	0.09	19.53
LAPTOP	0.66	146	0.3	62.28	0.94	206.07
PRESSING IRON	21.46	4721.05	10.82	2381.47	21.7	4773.47
ELECTRIC KETTLE	19.15	4213.91	9.53	2096.19	18.8	4135.96
ELECTRIC STOVE	16.38	3604.12	8.26	1817.62	16.23	3571.33



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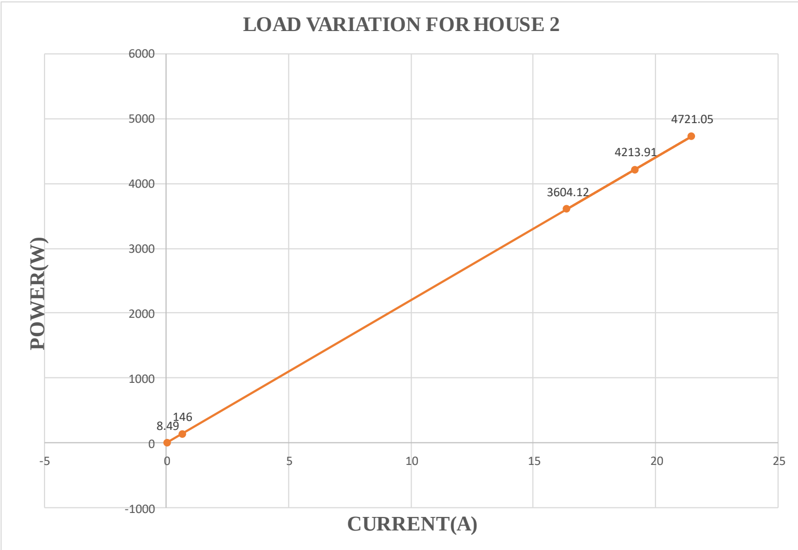

Figure 0.2: Graphical representation of the results obtained

The data and the graph above, shows that power consumed by the appliances went go below the preset values used in the Proteus design suite 8.10 simulation, thereby triggering the display of energy theft detected on a certain phase.

4.2. Results

The systems ability to correctly identify the power theft and recognize legitimate power consumption was analyzed. This was done to determine the reliability of the current sensors attached to the distribution lines.

The plate 1, shows the result of the system when load is connected to the legal load point and when it is connected to one of the illegal load points.

Plate 1: Result of the system for legal load and illegal load

V. Conclusion

Conclusively, this work has been able to prove that incidents of energy theft on distribution lines can be drastically reduced without having to be on site of the illegal premises. It has also proved that the reliability of the distribution network is possible and utility costs on the legal consumers can be reduced.

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