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Development of a Low-Cost Arduino Based Power Theft Monitoring Meter

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Abstract—Illegal electricity connections are common malpractice in the developing countries. Power theft has resulted in more losses at the distribution side incurred by service providers. The utility supplier experiences economical losses which leads to high electricity bills being charged on the consumer. This also contributes to distribution system experiencing high technical power losses and transformer damages due to unbalanced or overloading conditions on a single phase. The design and development of a real time low-cost power theft monitoring meter has been addressed in this paper. The established metering system has the capabilities to trace and capture any power anomalies based on comparison of power bought and power used by the end user. ESP01 module was used to upload voltage, current and power to ThingSpeak platform, where the operator can monitor power consumed at the end user remotely in real time using a computer or Mobile App. The adequacy of the prototype was tested based on conducted experiments and the results confirms the applicability of the device. The study implementation of the extensively sized device will help in minimizing both technical and financial power losses and faults in the system due to power theft.

Keywords— Energy meter, ESP01 module, Mobile App ThingSpeak, Power theft.

I. Introduction

Power theft is an illegal act of using unpaid utility electricity. This has grown into a major challenge in most fast-growing developing countries including South Africa, Kenya and Malawi. In a report done in Malaysia, 587 (86%) suspected areas out of 684 inspected were confirmed to have tampered with the utility power meters. The power theft normally happens at two common points which are, by the energy meter installed at the household level and/or at the distribution pole line. As much as there is unavoidable major technical losses at the distribution networks which have been tackled by various techniques [1][2], an unknown amount is still lost through illegal connections, meter tampering, unpaid bills and billing irregularities [3],[4],[5]. These malpractices tend to cause unbalanced overloading conditions on three phase distribution networks, leading to transformer damage due to overheating. The consumers are normally forced to dig deep into their pockets by the utility to incur for the extra losses due to power theft since this significantly contribute to non-technical losses in the system.

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Recent developments in smart grid technologies in the power sector, have introduced smart meters and other intelligent sensors which allow a two-way communication on the electricity usage. With access to such information, it can permit for acquired data to be used to detect power theft in the network.

According to Mishra *et al.* [6], power theft monitoring using Zigbee approach, provided an easy way to detect a wireless power theft without any human interface. It pinpointed the location and distribution section where there was unauthorized taping in real time. In [7], a review on development of various load monitoring methods were presented to determine effective practical applications. Monitoring and control at the demand side had room for more research in coordinating smart applications. Mangat *et al.* [4] proposed deep learning in neural networks which used the end user consumption data to monitor power theft with use of energy meter. Despite reduced cost in application of the method, its complexity in high level programming and determining the cost benefit analysis posed a challenge.

From the comprehensive review on power theft experiences in India [5], various challenges were identified in different methods proposed from the literature. It was noted that there is still a rise in power theft, despite the different measures being put in place since at times it is a well-organized syndicate with technical know-how of how the system operates. In [8], Radio Frequency (RF)-Transmitter based monitoring system was utilized whereby the RF received transmitted power from the utility which then provided a reception acknowledgement of consumed power, by activating a microswitch. The acknowledged information was transmitted to the utility control center via RF-Transmitter. When there was power theft in the system, an alarm accompanied by message alert with a heavy levy fine was sent. A systematic comparative analysis and future research opportunities were highlighted in [9]. Most of the Energy Theft Techniques (ETDs) proposed used state of art techniques but lacked in effective power theft tracking.

Jain and Verma [10] employed phasor measurement units to communicate with the master controller for feeder overcurrent protection and power theft detection at the substation/distribution transformer in a real time simulator. This would also assist in power consumption billing at the distribution network. An inbuilt system in smart meters was proposed in [11] to monitor power theft. Data was to be monitored at regular intervals by an automated wireless meter reading system and transmitted via a GSM module. The difference between the delivered power data and predetermined power bought will lead to ascertain of any power theft in the network.

A wireless ZigBee technique was employed in [8], to detect any bypassing of electricity connections and control revenue losses by the utility. An accurate billing system of consumed electricity is used to prevent any power theft in the network. If any theft is detected, the power supply for the end user bypassing the energy meter will be cut off from the supply and can only be connected back by an authorized person. Authors in [12], proposed an IOT based energy theft detector with an alert system. If theft was detected the whole distribution line would be cut off to prevent any further theft. This can be a limitation for the other consumers who will be affected by such a development.

The paper looked at the design and development of an Arduino based energy monitoring system. The prototype assisted with wireless monitoring of energy use with an assumption of detecting any power theft presumed in the distribution network by the utility company.

II. Development of the Energy Monitoring System

A. Overview

This section explains the development of the energy monitoring system. The execution of the design is also elaborated in detail. *Fig. 1* shows the system block diagram of the energy monitoring system.

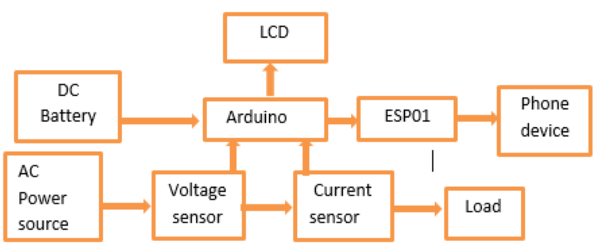

Fig 1. Block diagram of the energy monitoring system

The Arduino microcontroller and the rest of the connected components required 5V DC supply whilst the 230volts AC supply powered the voltage and current sensor as it measures energy consumed by the load. The consumed power was displayed on the LCD screen. ESP01 Module was used to monitor the reading of the energy meter via ThingSpeak platform website which can also be accessed through the mobile App.

Fig. 2 shows the line diagram for the energy meter connection from the distribution point to the load. The energy meter shall be the key point to monitor any power theft before and after the meter. Detection of any bypass connection and the actual energy consumed by the end user is transmitted to the utility service.

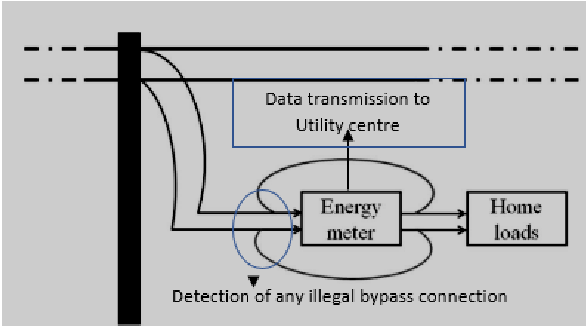

Fig 2. Line diagram for the energy meter connection

B. Mathematical Formulation

If the units purchased and the total amount of consumed power by the end user are not equivalent and differ with a huge margin, this gives a clear indication of possible power theft [11].

$$\sum P_{unitsbought} = \sum P_{consumed} + P_{Loss} \tag{1}$$

$$P_{Loss} = P_{in} - P_{out} \tag{2}$$

where; $P_{unitsbought}$ = *Units purchased*
$P_{consumed}$ = *Units consumed*
P_{Loss} = *Power losses in the system*

To correct *Aggregated Technical and Commercial* losses in the electrical system and predict whether there is power theft or not;

$$ATC_{losses} = \frac{\left(Energy_{input} - Energy_{Billed}\right)}{Energy_{input}} \tag{3}$$

$$Theft = \sum_{i=1}^{n} (Input\ units - Payable\ units - \text{losses}_i) \tag{4}$$

Real power consumed at the end user is;

$$Power = V \times I \times cos\phi \tag{5}$$

C. Software Development

The circuit diagram shown in *fig. 3* was designed in Proteus software tool, developed by LABCENTER ELECTRONICS purposely for Electrical and Electronic circuit designs. It is a robust, dynamic and flexible Computer Aided Design open-source software, equipped with 2D CAD drawing features integrated with 3D circuit visualization abilities which comes in handy when trying to produce a PCB fabrication. Proteus can be easily interfaced with Arduino programming to simulate the system and imitate real time before implementing an actual hardware prototype.

When the system is activated and initialized, it senses if there is power supplied to the load (end user). If power is consumed, the sensor will monitor the supply voltage and consumed current in the network to the load.

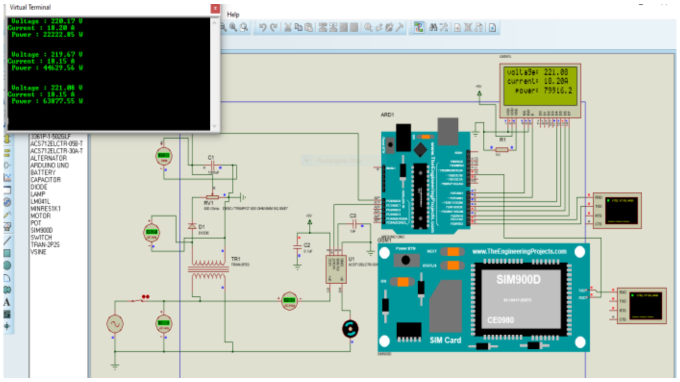

Fig 3. Circuit Diagram of the energy monitoring system

The sensed data is displayed on the LCD and recorded online via ESP01 module in real-time. The recorded data is stored on the ThingSpeak platform where voltage, current and power consumed by the end user is uploaded and accessed via a smart phone or computer. The developed Arduino program followed the instructions as executed in the system flow chart in *fig.4*. The two main outputs were an LCD display and an ESP module which allows the Arduino to connect over the *Wi-Fi* network and connect to *TCP/IP* to enable transmission of recorded data to ThingSpeak platform. Since the ESP module library was inaccessible, a GSM module was used to transmit the recorded data to the virtual terminal for simulation purpose.

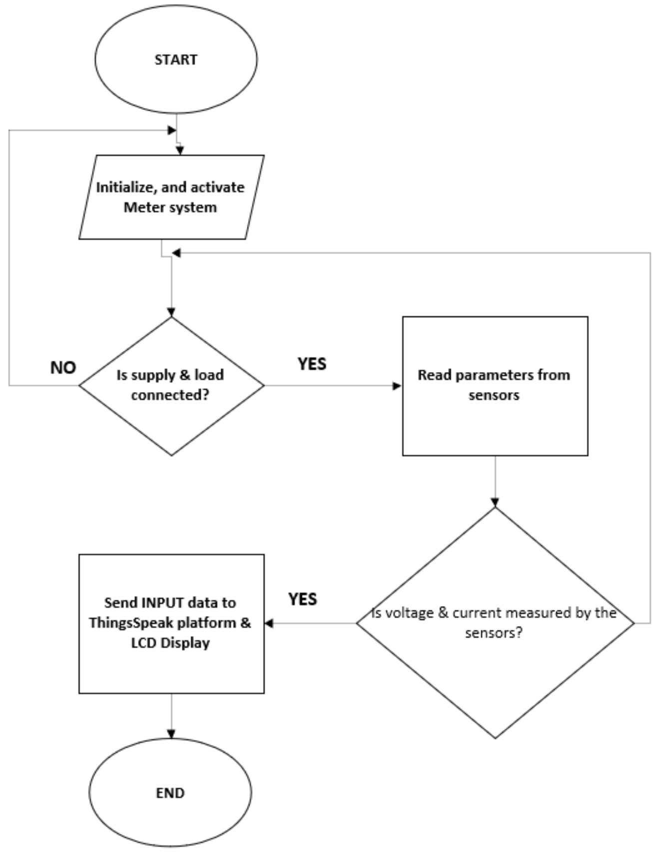

Fig 4. System flowchart

D. Hardware Implementation

The developed hardware prototype was tested in a laboratory set up at TCRET lab center (Mzuzu University) to evaluate its performance. The practical implementation of the system prototype was first achieved on a breadboard mounting depicted in *fig. 5 and 6*. During testing, the AC voltage supply and current were measured from the multimeter and compared with the results collected from the energy meter. The results displayed on the LCD and the measured parameters from the multimeter were similar, proving the system functionality to work as expected.

Power consumed was determined by the voltage supply and current sensed, monitored through the energy meter using the *equation (5).* A complete prototype of the working system connected between the mains AC supply and the load which represented the end user is shown in *fig. 7*. A *6W* bulb and an electric iron rated *1100 W max* were used as loads in this experiment.

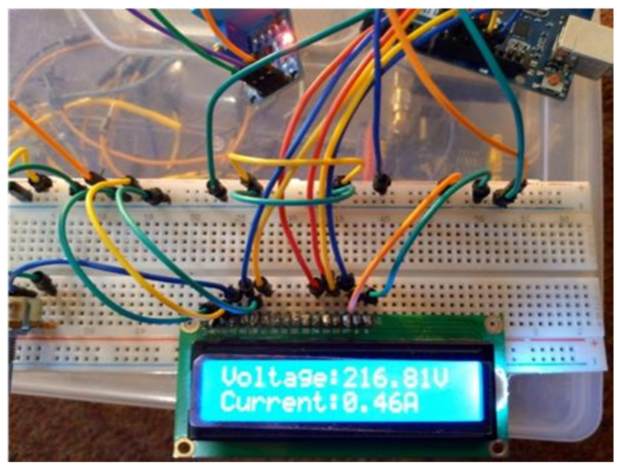

Fig 5. Breadboard tests

Fig 6. Screenshot showing power consumption

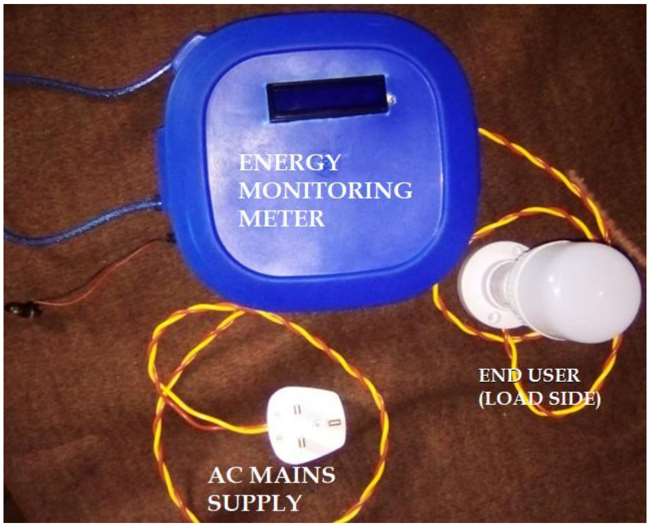

Fig 7. Energy Monitoring Meter connected between Supply and Load

III. Results and Discussion

A. *Evaluation of the energy meter system*

The system was tested and evaluated in both simulation and hardware set up to assess its functionality. The Proteus software simulation results shown in *fig. 8* considered a motor as an end user load connected to the mains AC supply. The monitored voltage, current, and accumulated power were printed on the Serial Monitor of the Arduino IDE Virtual Terminal and on the LCD. In the simulation the load was assumed to be from a heavy user household whereby the current which was being drawn with time was very huge (about *18A*). The power consumed after a time lapse of 1hr 30min was *288219.25W*. It can be noted how the accumulated power increased with time from the 3 snapshots taken.

The Virtual Terminal represented a remote device which captures the monitored data via the GSM module in a form of SMS. There was very small difference in the recorded parameters on both displays. Based on the software, the system proved to be accurate on sensed voltage, current and the accumulated power with a minor error difference.

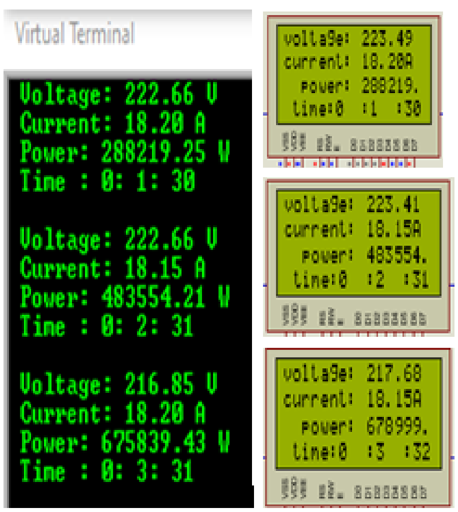

Fig 8. Proteus Simulation Results

The hardware implementation employed the use of ESP01 module to send the monitored data to ThingSpeak platform. The Energy Meter remotely monitored the voltage, current and accumulated power, through a mobile app or computer. The prototype worked successfully.

B. *Analysis of the collected data*

A *6W* bulb was connected to the load on a day when supply was coming from a PV system. Therefore, it can be noted that the voltages recorded were fluctuating between (215-230V AC). *Fig. 9* shows the graphs for the current and cumulative power consumed by the bulb in real-time was about *33W* which recorded in 4 hours 49 minutes.

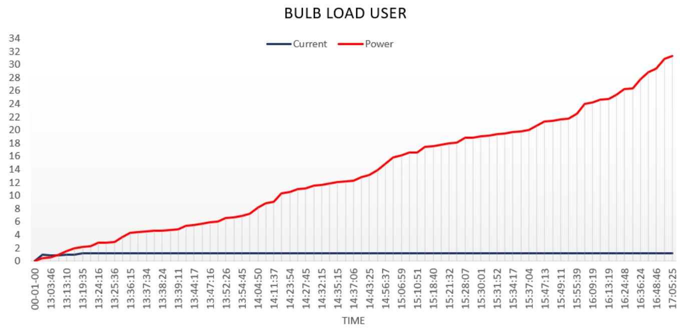

Fig 9. Consumption for Bulb load usage

A 0.95-*1.1kW* rated electric iron was connected to the load on a day when supply was from the utility grid. On this day the power source was from ESCOM and the voltage supply was reasonably stable (220V AC). The current drawn was nearly constant after the first 3 minutes when the iron had heated to the set condition as depicted in *fig. 10.* The cumulative consumed power was about *66W* after 1 hour 21 minutes.

The designed system was able to measure and monitor the power consumed by the loads. The data obtained from the simulations gave high insights on the implementation of the design. On implementing the hardware prototype, the measured values of the various parameters were within the acceptable ranges. The data uploaded on ThingSpeak matched the displayed data from the LCD.

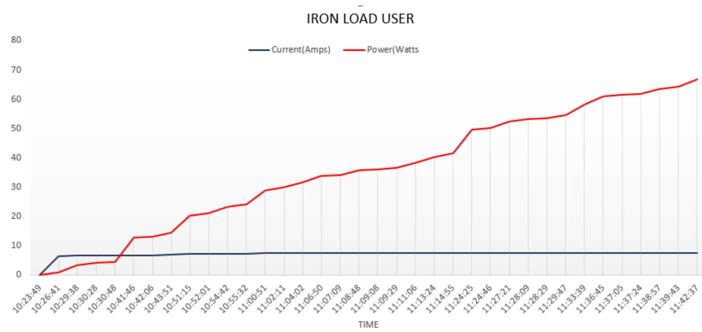

Fig 10. Consumption for Iron load usage

At times the voltage supply was unstable which may have caused the system to record results deviating from the expected accuracy level. When the load is disconnected, the current drawn was *0A* and there was no power consumption thus the energy meter would maintain the reading of the last previously accumulated power by the end user. It would only continue to update the records when the end user is connected again. The monitored energy consumed by the developed system will then be compared to the actual power that would have been purchased by the end user, enabling the utility supplier to equate with the units sold at each specific load connection.

IV. CONCLUSION

The designed energy meter gave a better perspective of how the power theft monitoring can be achieved by the utility supplier by incorporating low-cost components with convenience and in an efficient manner. This can have a huge impact in assisting with reduction in technical and economical energy losses due to theft while ensuring people with illegal connections are penalized for the extra consumed charges which will have been monitored by the system. It will also enable safe connections by the consumers connected to the electrical network, while maximizing profits from electricity bills in proportion to the power consumed by end user. It can be highlighted how the system is able to inform on the quality of the voltage supplied by the utility.

The developed system was reliable to a certain extent due to unavoidable limitations but can be scaled up and improved further. Due to the utility unavailability of data on purchased power or units by the customers, the system was limited to lab set up. Assuming that the units bought are known the difference can be detected if there will be an imbalance on the units bought and power consumed in the network. The difference can determine whether there is power theft or not. The main challenge of the system was failure in transmission of data at times when there was weak internet connection which led to failure on the ESP01 module in uploading data to ThingSpeak platform for record in real time.

For future works, it is proposed to integrate the system with the utility payment system to be able to automatically match the units bought with the power that will been consumed at a certain point/load connection. An alert and precise location must be detected in the event of illegal connection or suspicious tampering to the system at the load side.

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