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New consumer load prototype for electricity theft monitoring

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Abstract. Illegal connection which is direct connection to the distribution feeder and tampering of energy meter has been identified as a major process through which nefarious consumers steal electricity on low voltage distribution system. This has contributed enormously to the revenue losses incurred by the power and energy providers. A Consumer Load Prototype (CLP) is constructed and proposed in this study in order to understand the best possible pattern through which the stealing process is effected in real life power consumption. The construction of consumer load prototype will facilitate real time simulation and data collection for the monitoring and detection of electricity theft on low voltage distribution system. The prototype involves electrical design and construction of consumer loads with application of various standard regulations from Institution of Engineering and Technology (IET), formerly known as Institution of Electrical Engineers (IEE). LABVIEW platform was used for data acquisition and the data shows a good representation of the connected loads. The prototype will assist researchers and power utilities, currently facing challenges in getting real time data for the study and monitoring of electricity theft. The simulation of electricity theft in real time is one of the contributions of this prototype. Similarly, the power and energy community including students will appreciate the practical approach which the prototype provides for real time information rather than software simulation which has hitherto been used in the study of electricity theft.

1. Introduction

One of the major challenges facing power providers worldwide is electricity theft which is the practice of using electricity from the utility company without the company's authorization or consent. Electricity theft, which could be in form of billing irregularities, meter tampering, and illegal connection and unpaid bills is commonly carried out at the consumer end, [1]. The prevalence of electricity theft in developing countries range from 20 to 30% losses in the distribution network [2], and [3] reported a wider range of 10 - 40%. Recent worldwide report indicates an increase in theft records as well as numbers of offenders include residential customers. American Electric Power reported 27% increase in electricity theft between January and February 2009 as compared to previous year [4]. Similarly, investigation of 14,000 customers by PECO Energy Company, (USA), in early 2008, showed 30% electricity pilfering [4].

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Furthermore, the consequence of this menace, in terms of revenue loss, is well evident in developed countries such as the USA and Canada which recorded huge revenue loss, amounting to $6 billion and $100 million, respectively, to electricity theft in 2010 [5-6]. Similarly, fast developing countries, such as Malaysia, reported a revenue loss ranging from RM150million to RM500 million, between 2010 and 2011, [7-8]. In addition, losses amounting to US$32 million due to electricity theft was recorded by Jamaica Public Service Company (JPS) in 2012 [9] while losses recorded in South Africa ranged between R2.5 billion and R3.6 billion also in 2012 [10-11].

Billing irregularities, non-payment by the consumers, illegal connections, meter tampering and metering errors, have been identified as the widespread operations under electricity theft [12]. The most prominent being illegal connection and meter tampering and various ways of tampering with energy meter are elucidated in [13]. Basically, electricity theft often results to overloading of the generation units and this adversely affects the utility company in terms of revenue losses [14]. Besides, electricity theft poses health hazard as well as safety concerns leading to death and maiming of personnel [15-18]. Hence, the need to prevent and minimize these adverse impacts of electricity theft has attracted the interest of this study.

Various schemes have been designed to solve the problem [19-20] however, recent reports indicate that the menace has not been managed properly, because the prevalence of the electricity theft is mushrooming at alarming rate and the perpetrators are becoming sophisticated as technology advances [21]. Consequently, the detection and minimization of electricity theft remains one of the major challenges in the distribution network, even as several methods proposed for their amelioration are either not implementable in real time or yet to be applied in real situations. This paper discusses the problem of electricity theft and elaborates on the proposed prototype for the study of electricity theft in real time.

2. Literature review

Detailed review of several techniques proposed and developed by various researchers, over the years, for the detection and estimation of electricity theft can be found in [22]. In [23-25], automatic meter reading system incorporated with tampering detection and various communication media such as Global System for Mobile Communications (GSM) as well as Zigbee, to track electricity theft have been proposed. [2, 26-29] employed artificial intelligent system such as Support Vector Machine (SVM) to classify electricity theft based on the energy consumption pattern of the consumer and pre-select suspected consumers for inspection.

In addition, the power line impedance technique proposed in [30], involves disconnection of subscribers and that a low voltage signal of 2V at 150Hz would be transmitted to the network to detect impedance of the network. Comparisons were made with the installed impedance values and the difference indicates the theft location with respect to the location of legitimate consumer. On the other hand, [31] proposed Central Observer Meter (COM) to monitor and identify the perpetrators. The method proposed in [32] uses two energy meters to track illegal connection.

Meter tampering detection based on monitoring the live current, neutral current and the voltage at the meter input to detect various tampering have been proposed in [33]and the changes in their values depict electricity theft. [34] and [35] proposed the injection of unwanted harmonics into the distribution network in order to cause damage to the appliances of the suspected illegal users and application of smart resistance incorporated in Smart Meter as a mode of detecting illegal electricity usage, respectively.

3. The prototype design consideration

Consumer Load Prototype (CLP) in this study represents the loads of a typical domestic consumer connected to power distribution network in real life situation. The design of a consumer load prototype involves the architectural plan of consumer's building which depicts necessary information about the layout of the building and the electrical design with lighting outlets, socket outlets and switches symbols (Figure 1). This facilitates the calculation and selection of the materials needed for the final construction.

The level of illumination, type of illumination, height of fitting above the floor and the size of the room(s) were considered for number of lighting outlets. The control switches, for controlling the light, are located on the inner wall of the room, adjacent to the door. The socket outlets for fixed equipment are located at anticipated positions while the sockets for portable equipment were adequately provided.

The regulations and standards of the Institution of Engineering and Technology-IET and Wiring Regulations (BS 7671) were used to govern the design and installation of the electrical equipment and wiring. The installation contains efficient and effective earthing system, recommended by IEE regulations [36].

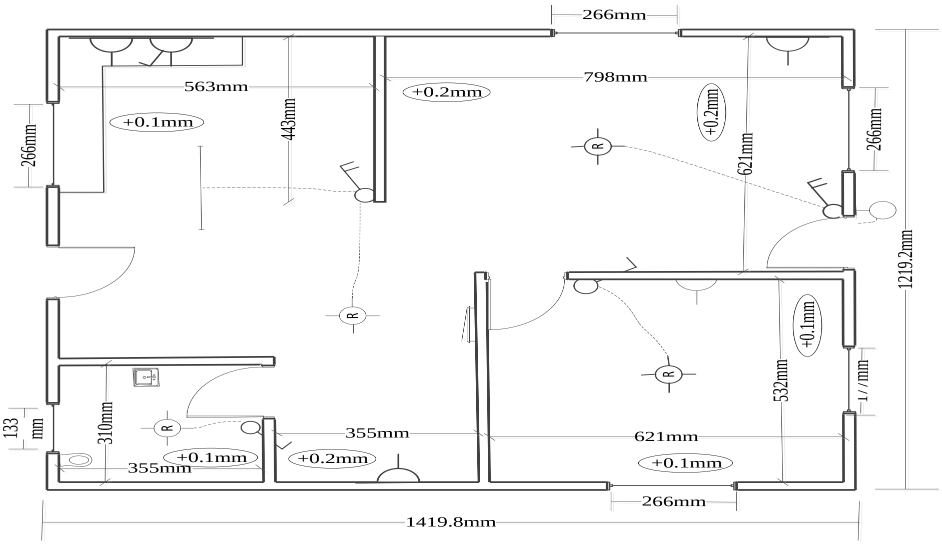


Figure 1. Electrical design of consumer load prototype.

3.1. Assumptions

The following assumptions were considered in the construction of the CLP.

1. A typical consumer house consisting of one bedroom apartment was chosen for the prototype design. This is to minimize the space, construction cost and moreover, most of the household electrical loads can be represented adequately without large deviation from those used by typical domestic consumers.

2. The consumer building is assumed to occupy a 9144mm by 7924mm in area (comprising a bedroom, a living room, dining, toilet, laundry and kitchen as detailed in Table 1).

3. Voltage supply is 240V

Table 1: Dimensions on the Plan and the Prototype**.**

	Actual house dimension (*mm*)	Plan dimension (*in*)	Prototype dimension *(mm)*
Room 1	4267 x 3657	2.80 x 2.40	621 x 532
Living room	4877 x 4267	3.60 x 2.80	798 x 621
Toilet	2438 x 2133	1.60x 1.40	355 x 310
Kitchen	3962 x 4267	2.54 x 2.80	563 x 621

4. Circuits system of the CLP
The consumer load consists of three types of sub-circuits which include the lighting sub-circuit, heating sub-circuit and power sub-circuit.

4.1. Lighting sub-circuits:
Lighting sub-circuit is usually rated at 5A according to IEE regulation A10. In deciding the number of lighting per circuit, the number of lighting outlet was obtained from the electrical design plan and minimum 100W per outlet is assumed IEE regulation. This means that the highest number of outlets that can be connected per circuit is 11, however, more than one circuit is preferable to prevent total darkness in case of fault. Lighting circuits was wired with 1.0mm or 1.5 mm cable while the cord suspending the pendant fitting is 0.5mm or 0.7mm.

4.2. Power sub-circuit
This is usually in form of socket outlet which could be either in ring circuit or radial circuit and are designed to provide a power source for portable power equipment. The most acceptable rating is 13A as indicated in IEE regulation A30-41. The usual number of sockets allowed in both ring and radial circuits is unlimited depending on the sizes of the room and type of cable used [37]. The kitchen was given a special consideration, due to the fact that loads are expected to be concentrated there. The assumed current for socket outlet is 13A according to IEE regulation A30-A41 and protected with 20A fuse radial connection

4.3. Heating sub-circuit:
Appliances such as air condition, cooker of higher rating and immersion water heater fitted to vessels in excess of 15 litres usually have separate circuit because of their current rating which is in excess of 15A and fused with 30 or 32A fuse (IEE regulation A26). Exception to this rule, as contained in the regulation A28 and A29, it allowed final sub-circuit to supply two cooking appliances if (i) they are in the same room (ii) situated within 2m apart and (iii) the combined rating does not exceed 30A. Otherwise, a separate cooker circuit is recommended and the current demand of the appliances shall be assessed according to the IEE regulation A27.

Table 2. Summary of main cable selection

Sub-circuit	Number of outlets	Actual current (A)	Applying Diversity factor	Main-sub circuits current	Cable size
Lighting	6	3.166	0.66 X 3.1	2.1A	1mm
Radial	4	20	100% of full load of largest circuit 40% of full load of all other circuits	Since it is one circuit =20A	2.5mm
Cooker/AC	1	30	the first 10 A of the cooker load 30% of the remainder 5A if the cooker unit has a socket outlet	17.5A	2.5mm
			Total	= 39.6A	

4.4. Selection of Cables for Sub-Main
Different factors considered in the selection of cable for sub-main circuit includes:
i. Capability to carry full load current
ii. The maximum permissible voltage drop ≤ 2.5% of supply voltage

iii. Method of insulation
iv. Grouping of the cables
v. Ambient temperature
vi. Class of excess current protection

In the selection of main cable that supply the consumer from the distribution feeder, diversity factor is applied to the sub-circuit as indicated in Table 2. The total current value is 39.6A. The equivalent cable, from [38], to this value is $4mm^2$ and, miniature circuit breaker of 45A rating was chosen as a protective device. The voltage drop which should not be greater than 2.5% of the supply voltage (240V) for the $4mm^2$ cables is 11mV/A/m [38]. The length of the cable is 5m and this leads to the calculation of the main sub-circuit which supply power to the consumer load and the selection of switchgears.

4.5. 4-way Distribution board
The distribution board or consumer unit is where various load sub-circuits and earthing arrangements are connected. It is partitioned into various sections with fuses or circuit breaker of different ratings to isolate the sub-circuit load in the event of a fault. These sections are known as 'ways' hence, the unit derives its name from the number of ways it is enclosed i.e. 4-way distribution board (5A circuit breaker- lighting sub-circuit; 20A circuit breaker- power sub-circuit; 32A circuit breaker-heating sub-circuit; 40A residual current device (additional protection).

4.6. Construction
All the components and wires were connected to form a complete Consumer Load Prototype (CLP). The final outlook of the prototype is shown in Figure 2 and the flow chart reflected in Figure 3.

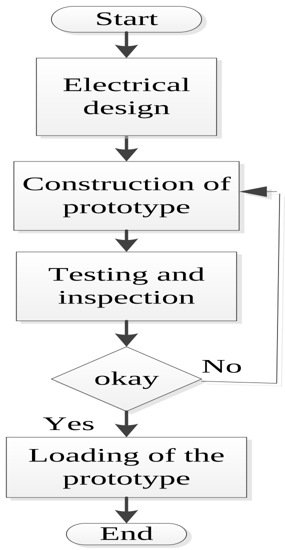


Figure 3: Flow chart for the Prototype development

Figure 2: Final outlook of the Prototype

5. Load monitoring and sensor selection
Current sensors detect the flow of current in a conductor and generate a signal (analog or digital) that is proportional to it. Current sensor is employed in order to monitor the loads connected to the prototype and acquire real time data. Rogowski coils, Current transformer and Hall Effect sensor are the most commonly used sensors for current detection in a conductor. One major advantage of these sensors is that they provide galvanic isolation between the power network, the operator and other instrument connected to them. Their selection is based on accuracy, drift, linearity, phase shift,

integration and cost, however Hall Effect current sensor (ACS785, Allegro MicroSystem Inc., USA) was chosen based on its size and other advantages expressed in [39] having satisfied the selection criteria.

Energy meter (misa SDN BHD, Malaysia) as well as Hall Effect sensors was connected to the prototype, while the meter shows the energy consumption in kWh, the sensors acquired the current data, via the labview hardware and software, which is used for monitoring purpose. Finally, the reading of the energy meter was benchmarked with the output of the sensors.

5.1. Experimental set up

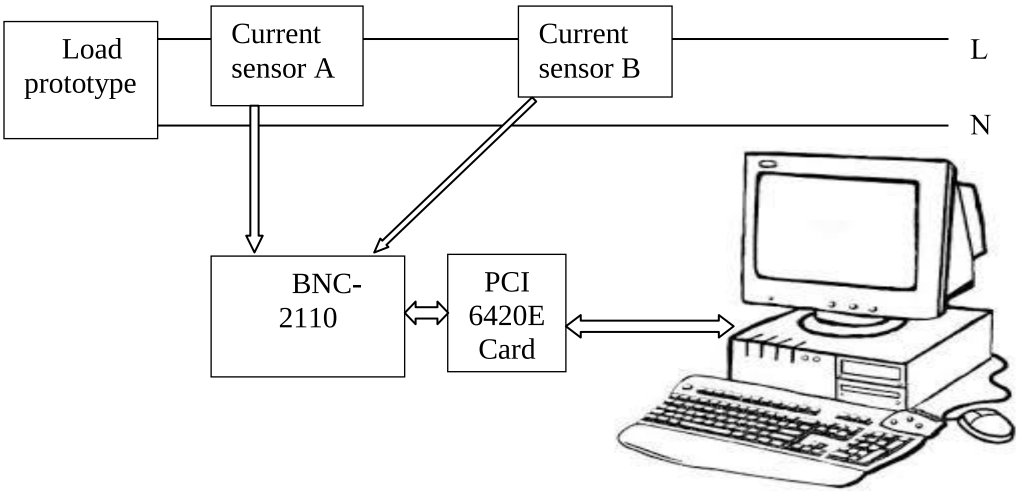


Figure 4. Block diagram of the monitoring system

Real time information was fed directly from the sensors attached to the conductor feeding the prototype both at the prototype terminal and power source (pole). The sensors were connected to (BNC-2110, National Instrument, USA) device which is linked to the PCI 6420E channel in the computer. The software programme was configured to log acquired data directly into the computer hard disk as well as show the monitoring processes in real time Figure 5. Data acquired were stored for further analysis.

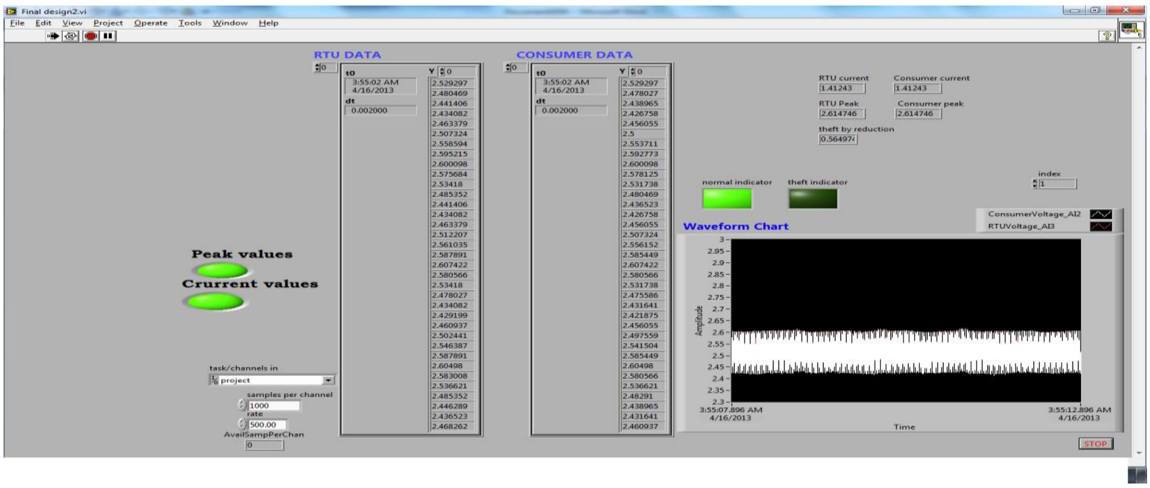
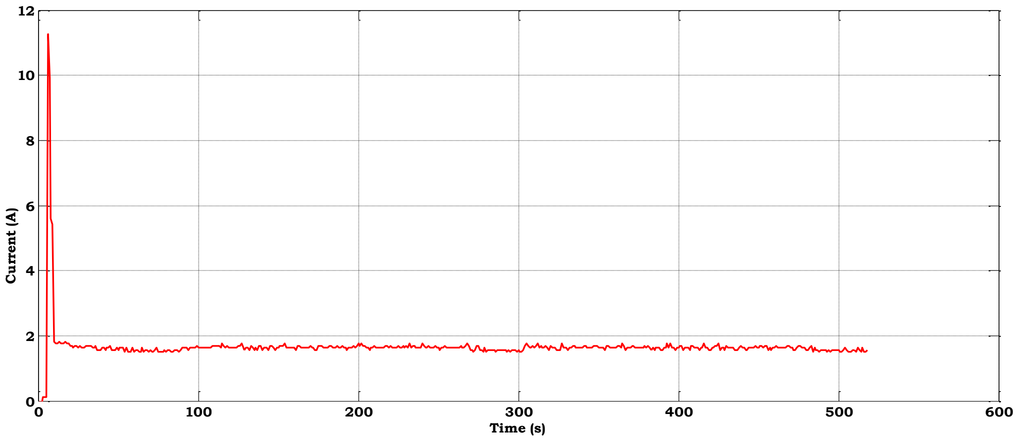


Figure 5. Real time load monitoring system using Labview platform

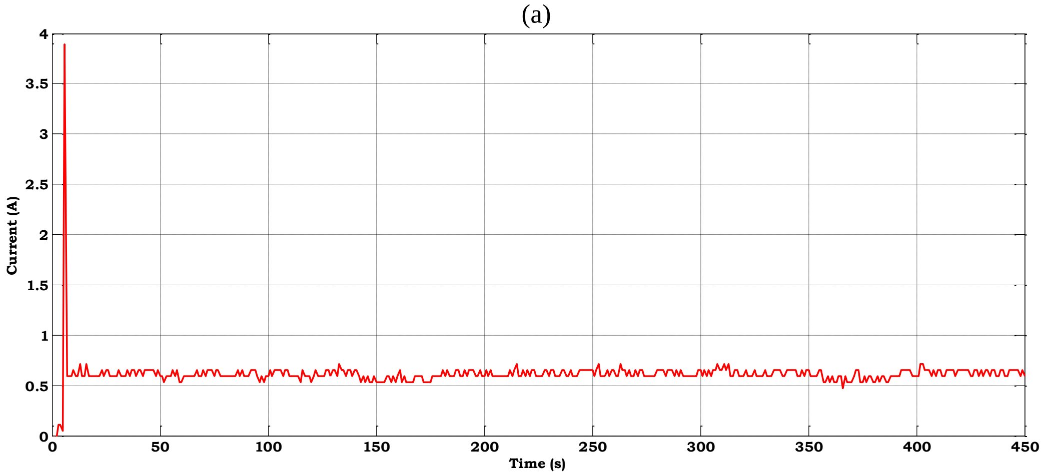
6. Result and discussion

The prototype was connected to power source and the loads including: refrigerator, incandescence bulb (100W), fluorescence lamp (80W), table fan (40W), and electric kettle (1500W) were connected for 15minutes each accordingly. The energy consumption of these loads was monitored through the energy meter as well as the real time data acquired through the current sensors (ACS 758) connected to the prototype via LABVIEW platform. Figure 6a to 6e show the graph of the individual load. A rapid increase in load consumption pattern was observed whenever the switch was ON, this is due to the effect of the switches contact during this period.

However, this rapid increase is pronounced in the current value of the refrigerator (Figure 6a) when it was switched ON. This was due to the single phase induction motor that drives the compressor and it is the major component in the refrigerator that consumes energy. It takes six to ten times it running current value at starting point [40]. Figure 7 illustrates the graph of the total load connected to the prototype and switch ON at 15 minute interval for about one hour 15miniute. It was observed that the time for electric kettle was shorter and fixed, this is because it is controlled automatically by the control switch which goes OFF when the water boils and corresponds to the time it took to boil 1.5liter of water. These observations suggest that the energy consumed by the loads connected to the prototype representing a typical consumer can be measured, monitored, studied and detected in real time. Furthermore, the consumer behaviour with respect to illegal activities such as electricity theft on the distribution network can be detected based on the consumer load pattern which is acquired through the sensors. Hence this could assists in the development of new algorithm for real time electricity theft detection and monitoring.



(a)



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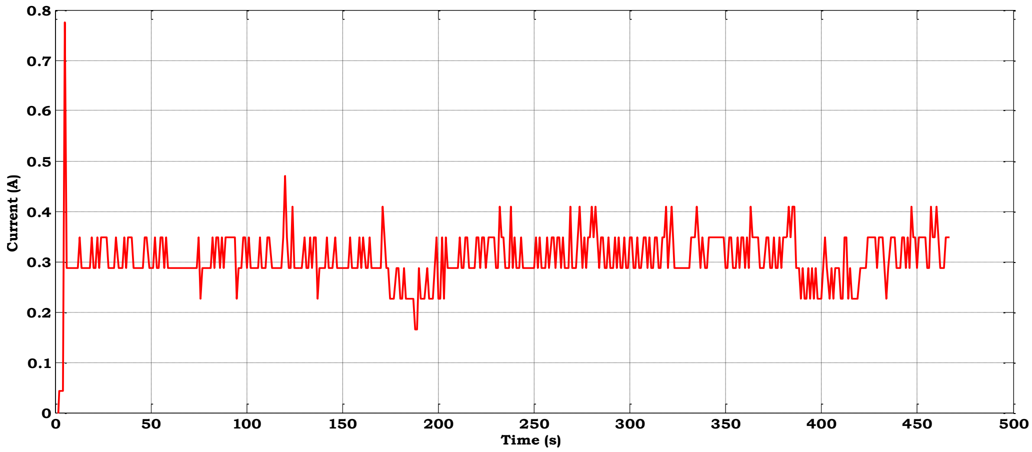

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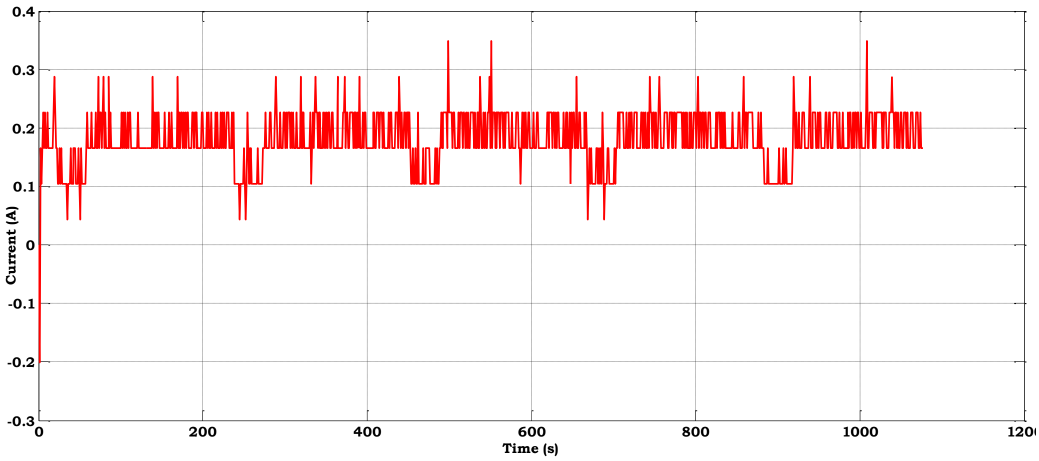

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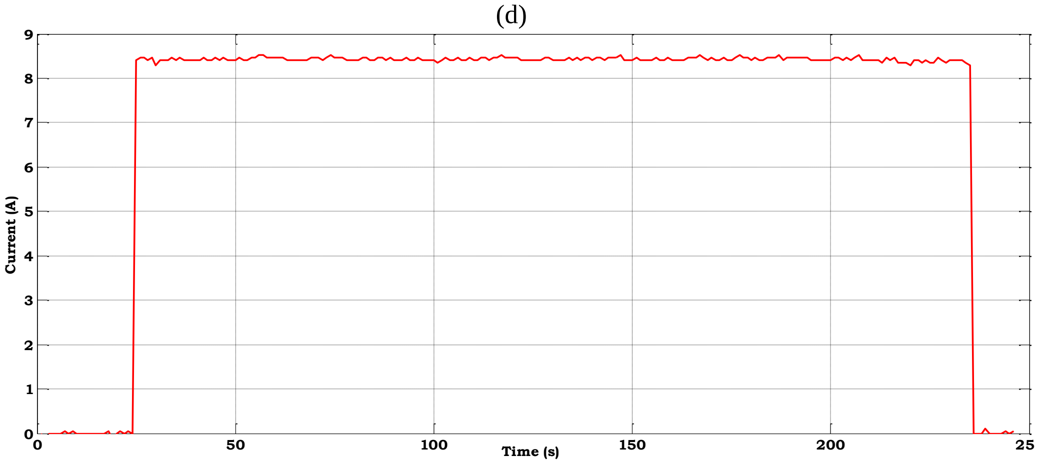

(e)

Figure 6. 15minutes load simulation graph : (a) Refrigerator, (b) Incandescence bulb, (c) Fluorescence lamp, (d) Table fan and (e) Electric kettle graph

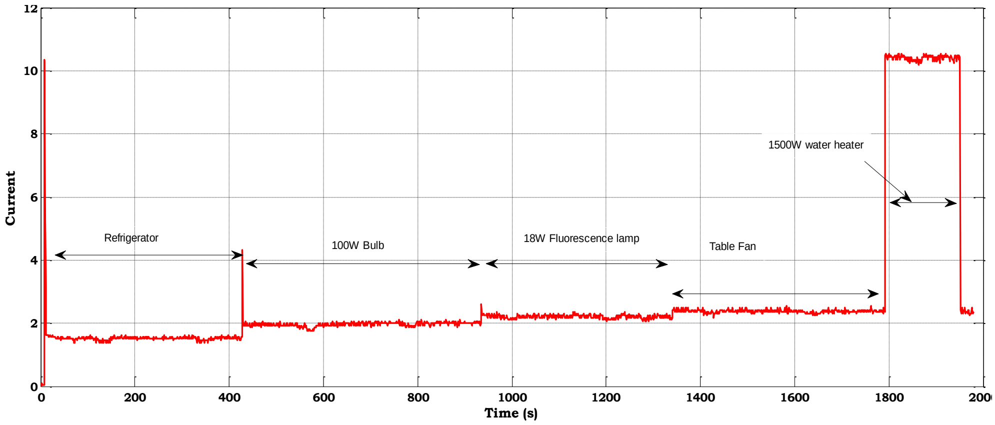

Figure 7. Combined loads at 15minutes interval

7. Conclusion

A CLP has been designed and constructed for the study of electricity theft in this paper. The Prototype which was constructed on a 4ft by 8ft plywood will facilitate real time simulation and data collection for the monitoring of electricity theft on low voltage distribution system. Standard regulations from Institution of Engineering and Technology (IET) were used to standardise the prototype. The ability to generate real time data for the study of electricity theft monitoring is considered as one of the contributions of this prototype.

The prototype will assist researchers and power utilities alike who are facing challenges in getting real time data for the study and monitoring of electricity theft. Similarly, the power and energy community including students will appreciate the practical approach from which the prototype provides real time information rather than software simulation which has hitherto been used in the study of electricity theft. Future work is to analyse the acquired data using advance signal processing and intelligent system techniques so as to study consumers' power consumption and to detect electricity theft.

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