

## Design and Simulation of Single Phase Intelligent Prepaid Energy Meter.

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### Abstract

In this paper, the design and simulation of Intelligent Prepaid Energy Meter (IPEM) has been presented. The objectives of this work are : (i) to model an IPEM,( ii) to show its reliability on load measurement ; and (iii) to show graphical behavior of energy consumption pattern of different loads connected to power supply. The design methodology is Artificial Intelligent (AI) based-using “ knowledge-based” and “cognitive simulation” approach. The intelligence properties and expected results of the proposed digital meter was modeled into the system; and was simulated using Matlab /Simulation tool. Results obtained were very satisfactory. If fully implemented, on one hand, the estimated bills or irregular billing imposed by Power Holding Company of Nigeria(PHCN) on her customers will stop; and on the other hand ,revenue loss through unpaid bills suffered by PHCN will greatly reduce. This will have an overall effects on the nation’s economy as revenue collection will increase.

**Keyword:**Artificial Intelligence, Prepaid Energy Meter, Model, Simulation, Matlab/Simulink

### 1. Introduction

Energy Meter is a device that measures the amount of electrical energy consumed by a residence, business, or an electrically powered device. They are typically calibrated in billing units and the most common one is the kilowatt hour, which is equal to the amount of energy used by a load of one kilowatt over a period of one hour, or 3,600,000 joules. Electricity meters operate by continuously measuring the instantaneous voltage (volts) and current (amperes) .The product of which gives the instantaneous electrical power (watts) which is then integrated against time to give energy used .

A Prepaid Energy Meter enables power utilities to collect electricity bills from the consumers prior to its consumption. The prepaid meter is also attributed with prepaid recharging ability and information exchange with the utilities pertaining to customer’s consumption details.. Literature has witnessed quite an amount of work in this area (Nwaoko, 2006; Omijeh, 2012)

## 2. Related Works

The use of electronic token prepayment metering has been widely used in UK for customers with poor record of payment. Shwehdi and Jackson (1996) in their paper, presented the Digital Tele-wattmeter System as an example of a microcontroller- based meter. The meter was implemented to transmit data on a monthly basis to a remote central office through dedicated telephone line and a pair of modems. It is only a stand- alone metering system.

Zhang et al (1998) utilized a DSP-based meter to measure the electricity consumption of multiple users in a residential area. A Personal Computer (PC) at the control centre was used to send commands to a remote meter, which in turn transmitted data back, using the power Line Communication (PLC) technique. The major problem with this system is that it cannot detect tampering by consumers.

A paper suggests a design of a system which can be used for data transmission between the personal computer and smart card. The device will transmit the data in half duplex mode (Kwan *et al*, 2002). In this paper, an Intelligent Prepaid Energy Meter has been designed, modeled and simulated using matlab/simulink tools. Koay et al (2003) in their work, designed and implemented a Bluetooth energy meter where several meters are in close proximity, communicated wirelessly with a Master PC. Distance coverage is a major set-back for this kind of system because the Bluetooth technology works effectively at close range.

In their paper, Scaradozzi and Conte (2003) viewed home- automation systems as Multiple Agent Systems (MAS). Home automation system was proposed where by home appliances and devices are controlled and maintained for home management. It is only a home management system and does not measure the amount of energy consumed by users. Hong and Ning (2005) in their paper, proposed the use of Automatic Meter Reading (AMR) using wireless networks. Some commercial AMR products use the internet for data transmission.

Stanescu et al(2006) present a design and implementation of SMS -based control for monitoring systems. The paper has three modules involving sensing unit for monitoring the complex applications. The SMS is used for status reporting such as power failure. Issues on billing system for electricity board usage were not considered. Prepaid meters can also make use of state of art technologies like WiMAX owing to the idea of centralized accounting, monitoring and charging. It brings telecommunication to the core of its activities to support more Smart Grid applications such as Demand Response and Plug-in electric vehicles (Khan *et al*, 2007). Prepayment polyphase electricity metering systems have also been developed consisting of local prepayment and a card reader based energy meter (Ling *et al*, 2010).

Malik et al (2009) in their paper, mainly focused on the controlling of home appliances remotely and providing security when the user is away from the place using an SMS- based wireless Home Appliance Control. In their

paper, Maheswari and Sivakumar (2009) aimed to develop an energy efficient and low cost solution for street lighting system using Global System for Mobile communication [GSM] and General Packet Radio Service [GPRS]. The whole set-up provides the remote operator to turn off the lights when not required, regulate the voltage supplied to the streetlights and prepare daily reports on glowing hours

Sharma and Shoeb (2011), in their paper suggested a method where we utilize telecommunication systems for automated transmission of data to facilitate bill generation at the server end and also to the customer via SMS, Email. Amit. and Mohnish (2011). Suggested in their paper, a prepaid energy meter behaving like a prepaid mobile phone. The meter contains a prepaid card analogous to mobile SIM card. The prepaid card communicates with the power utility using mobile communication infrastructure. Once the prepaid card is out of balance, the consumer load is disconnected from the utility supply by the contactor. The power utility can recharge the prepaid card remotely through mobile communication based on customer requests.

### **3. Design Methodology**

#### **3.1 Hardware Architecture of IPEM**

*IPEM* consist 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. 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 Matlab/Simulink designs and models of IPEM**

Simulink is a software package for modeling, simulating, and analyzing dynamical systems. It is integrated into the MATLAB (a high-level computer language for scientific computing and data visualization built around an interactive programming platform) environment. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Systems can also be multirate, i.e., have different parts that are sampled or updated at different rates. For modeling, Simulink provides a graphical user interface (GUI) for building models as block

diagrams, using click-and-drag mouse operations. Simulink includes a comprehensive block library of sinks, sources, linear and nonlinear components, and connectors. one can also customize and create your own blocks.. Models are hierarchical, so one can build models using both top-down and bottom-up approaches. Systems can be viewed at a high level, then double-click on blocks to go down through the levels to see increasing levels of model detail. This approach provides insight into how a model is organized and how its parts interact. After a model is defined, one can simulate it, using a choice of integration methods, either from the Simulink menus or by entering commands in MATLAB's command window. The menus are particularly convenient for interactive work, while the command-line approach is very useful for running a batch of simulations. Using scopes and other display blocks, one can see the simulation results while the simulation is running. In addition, one can change parameters and immediately see what happens, for "what if" exploration. The simulation results can be put in the MATLAB workspace for post processing and visualization. Model analysis tools include linearization and trimming tools, which can be accessed from the MATLAB command line, plus the many tools in MATLAB and its application toolboxes. And because MATLAB and Simulink are integrated, you can simulate, analyze, and revise your models in either environment at any point. An expert system of Fig. 1 was designed and developed in matlab/Simulink environment

#### **The Intelligent Prepaid Energy Meter (iPEM) model**

This block shown in Figure 2. models an a single phase energy meter that accepts utility power at its inputs (L and N) and consumer load at its output (L1 and N1). The block also provides the balance left in watt-hour at the wh port. The *supply status port* provides an indication of the supply to the load in rms voltage value. The block has a dialog parameter that indicates the meter ID for the grid network, which is read at the utility company.

**Power Factor Block:** The operation and calculation of the power factor is done here. See the internal computational architecture in Figure 5.

**VS Block :** It's a voltage sensor for sensing the input voltage from PUC

**Cs Block:** It's a Current source for sensing the current from the power Utility supply

**Diode Block:** It's program to rectify the ac signal to dc signals.

**C<sub>1</sub> block :** performs the filtering of the dc signal

**PS Block:-**It's Simulink converter which converts a the input physical signal to unitless simulink output signal

**Clock block :** It records the simulation time

**C2V Block :** converts the current signal to input voltage signals for the energy metering IC (ADE7756).

#### **4.Results and Discussions**

Consumer's Loads of different resistance values from 100 ohms to 1000 ohms (in steps of 100) were connected to the Modeled Intelligent Prepaid Energy Meter (IPEM). Readings and measurements were taken as shown in Table 4.1. The energy consumption behavior of a specific load was also monitored and recorded by IPEM.

i. It is observed from Table 1, that as the resistance of the connected Load reduces in value , the measured load increases in value. This satisfies the standard equation:

$$P = \frac{V^2}{R} \dots\dots\dots I$$

Where P = Measured Load in watt.

ii. From Table 1, the output current ( $I_{OUT}$ ) increases as the resistance value reduces. This satisfies ohm's law.

$$I = \frac{V}{R} \dots\dots\dots 2$$

iii. From Table 1, it is observed that, the percentage error of load measurement is  $\pm 0.03\%$  . Which shows high system accuracy and efficiency.

iv. It is observe From Fig 1, that the energy consumption pattern is linear. Which shows that the load is purely resistive. This satisfies the equation:

$$E = vit \dots\dots\dots 3$$

Where = Energy consumed, t = time (simulation time)

v. From Table 2, the percentage error of Energy consumed from meter measurement is 0.02%. This shows high system reliability and dependability.

vi. Fig.6 shows that the energy pattern of a purely resistive load is linear.

vii. From Fig.7, it is strongly observed that the Current and Voltage signals are in phase (i.e phase angle= $0^0$ ). Graph 1 shows a power factor (p.f) of unity (1).. This satisfies the expression;

$$p = vi \cos \theta \dots\dots\dots 4$$

Where  $\theta$  is the Phase Angle. v = output voltage, i=output current.

viii. Fig. 8.shows the variation of output signal as a result of noise or unregulated supply.

ix. Fig 9 shows that under impedance load, the energy consumption pattern is not linear. This satisfies the fact that the load is not purely resistive.

- x. From Fig 10, it was observed that under impedance load .( a) Output current and voltage where out of phase,(b) power factor was less than 1 It contains some components of “Inductive Loads or “Capacitive Loads” or both.

## 5. Conclusion

In this paper, a single phase Intelligent prepaid energy meter has been designed and modeled. It has a satisfactory efficiency in the measurement of rated load, power factor, output voltage, output current and system behavior. It is reliable in monitoring of energy consumption; and in graphical display of energy consumption behavior of different loads with different impedance. It also has the intelligence property of detecting peak energy consumption period which is a very important information for power utility company. This design is therefore recommended for implementation by power utility companies.

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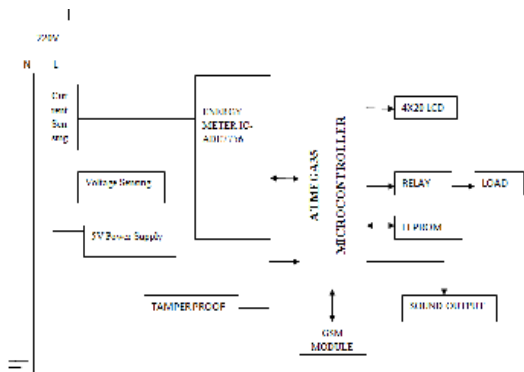
#### Authors' biography

**Bourdillon .O. Omijeh** holds a B.Eng Degree in Electrical/Electronic Engineering and M.Eng.Degree in Electronics/Telecommunications Engineering from Ambrose Alli University (A.A.U), Ekpoma and University of Port Harcourt respectively. His research areas include: Artificial Intelligence, Robotics, Embedded Systems Design, Modeling and Simulation of Dynamic systems, Intelligent Metering Systems, Automated Controls, Telecommunication and ICT. He is currently a Lecturer in the department of Electrical/Electronic Engineering, University of Port

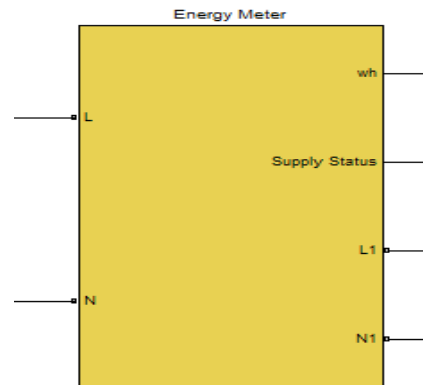


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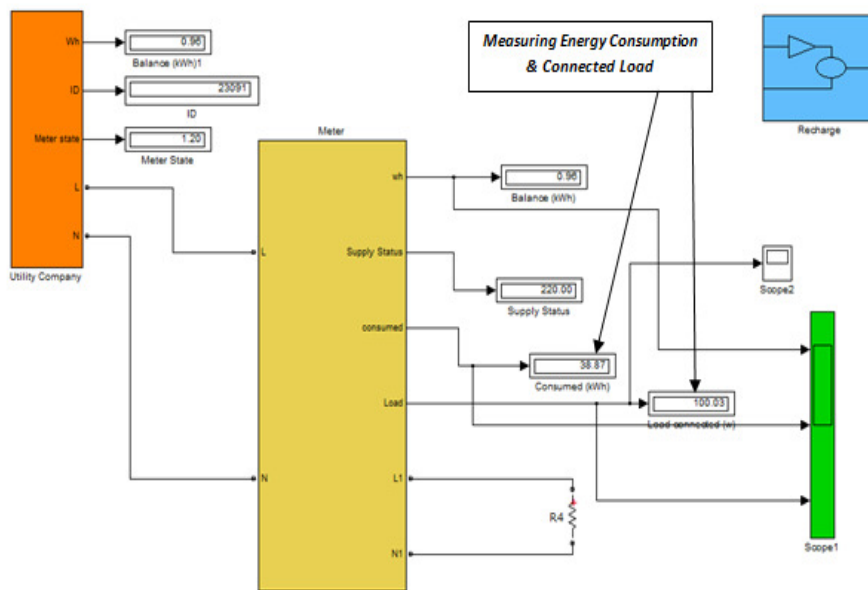




**Fig.1: Block diagram of Intelligent Prepaid Energy Meter (iPEM) hardware**



**Fig.2 The Intelligent Prepaid Energy Meter (iPEM) model**



**Fig. 3 Energy meter connection**

The Internal design architecture of this energy meter is shown in Figure 4.



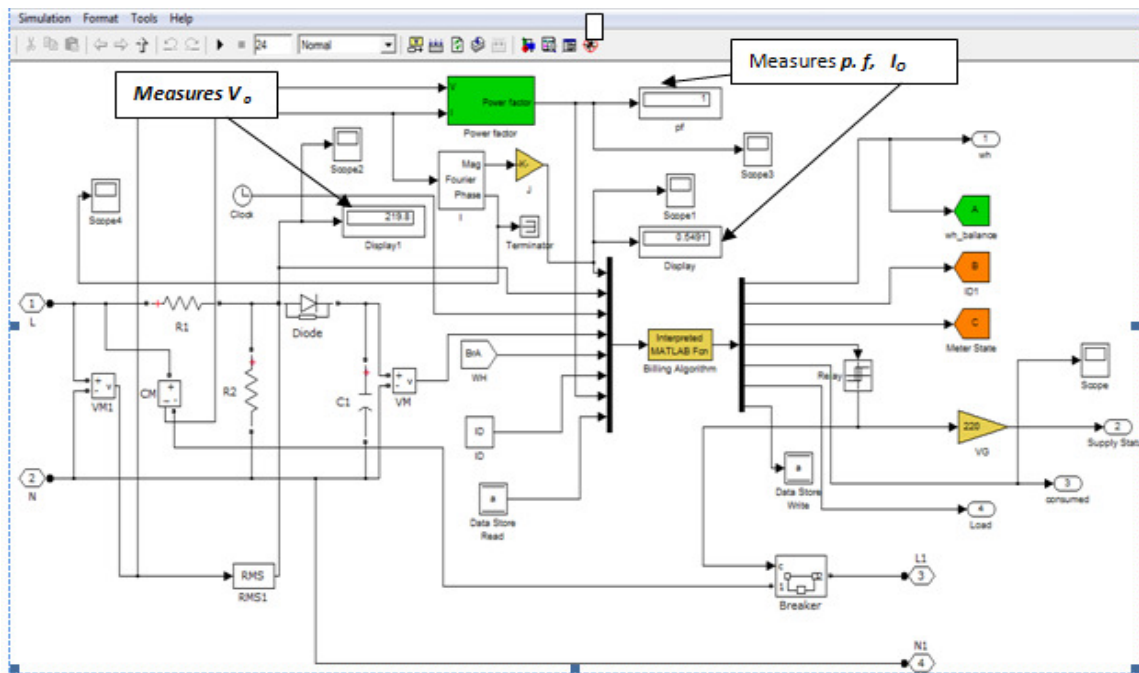


Fig. 4. Internal Architecture of Energy Meter block

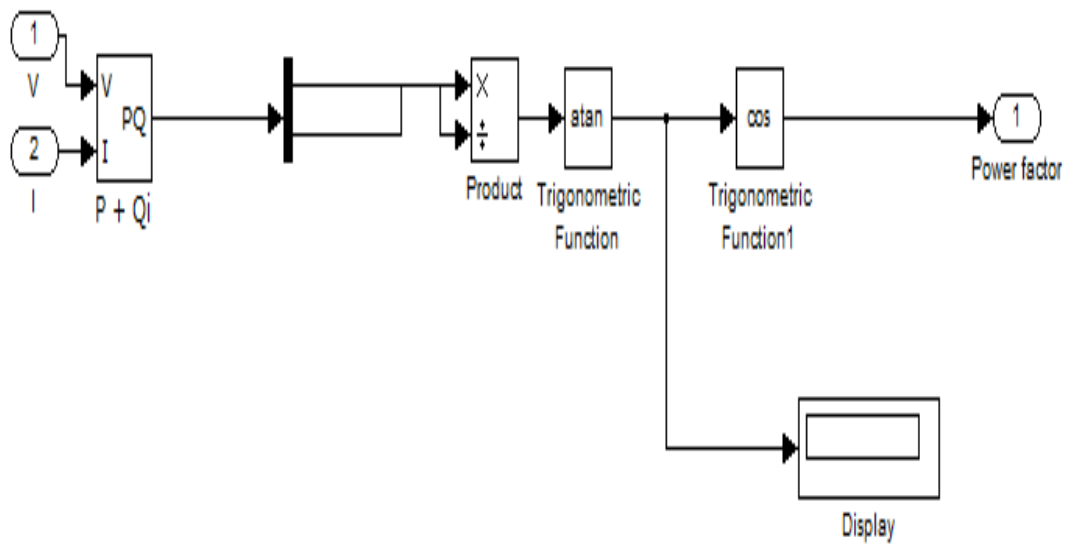


Fig.5: Internal architecture of the p.f block

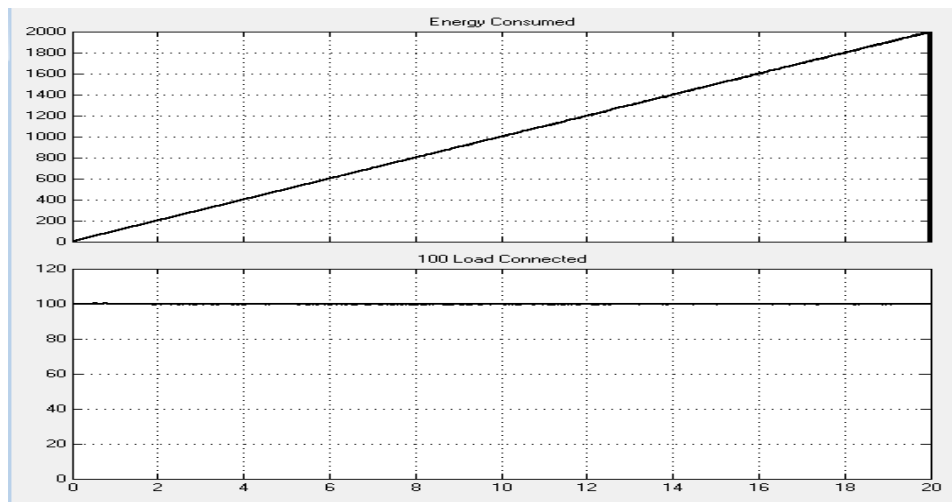


Fig 6: Display of Energy Consumption Pattern of a 100W connected Load



Fig. 7: Graphical Display of Measured  $I_o$ ,  $V_o$ , p.f. parameters.

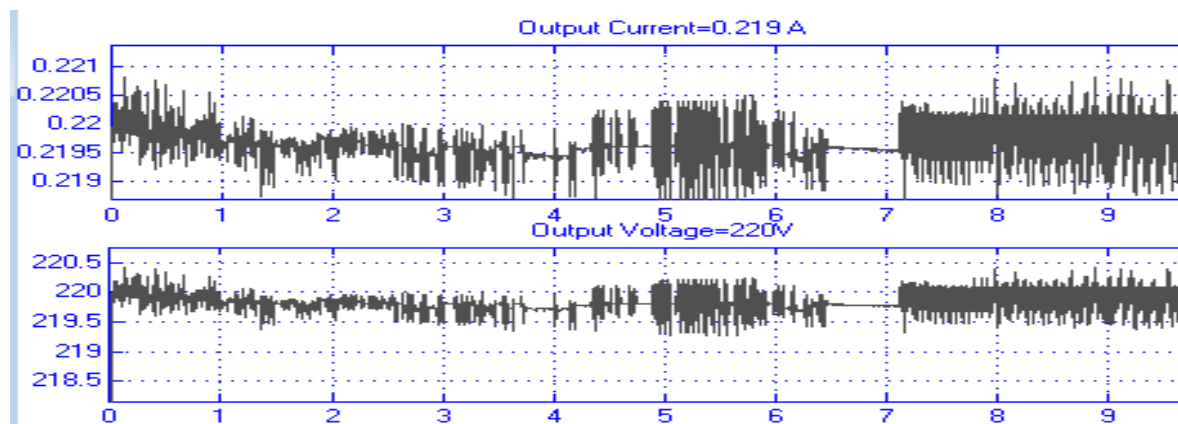


Fig .8 . Variation in output current and voltage signals

**Table 1: Measurements under varying Resistance of the connected Load.**

| SN | Resistance (ohm) | Calculated Load ( Watts) | MEASURED LOAD (W) | VOUT  | IOUT   | P.F | % Error (Load Measurement) |
|----|------------------|--------------------------|-------------------|-------|--------|-----|----------------------------|
| 1  | 1000             | 48.40                    | 48.40             | 220   | 0.219  | 1   | Not applicable             |
| 2  | 900              | 53.78                    | 53.77             | 219.9 | 0.244  | 1   | 0.02                       |
| 3  | 800              | 60.50                    | 60.49             | 219.9 | 0.2749 | 1   | 0.02                       |
| 4  | 700              | 69.14                    | 69.16             | 219.9 | 0.314  | 1   | -0.03                      |
| 5  | 600              | 80.67                    | 80.65             | 219.9 | 0.3666 | 1   | 0.03                       |
| 6  | 500              | 96.80                    | 96.83             | 219.9 | 0.4396 | 1   | -0.03                      |
| 7  | 400              | 121.00                   | 121.00            | 220.1 | 0.5508 | 1   | Not applicable             |
| 8  | 300              | 161.33                   | 161.36            | 219.9 | 0.7321 | 1   | -0.02                      |
| 9  | 200              | 242.00                   | 242.00            | 220.1 | 1.101  | 1   | Not applicable             |
| 10 | 100              | 484.00                   | 483.99            | 220   | 2.2    | 1   | -0.002                     |

Table 2: Reliability of the Modeled IPEM

| SN | Time (Hours) | Calculated Energy | Measured Energy | Percentage Error (%) |
|----|--------------|-------------------|-----------------|----------------------|
| 1  | 0.5          | 242               | 242.00          | Not applicable       |
| 2  | 1.0          | 484               | 483.99          | 0.0020               |
| 3  | 1.5          | 726               | 725.99          | 0.0014               |
| 4  | 2.0          | 968               | 967.98          | 0.0020               |
| 5  | 2.5          | 1210              | 1209.98         | 0.0020               |

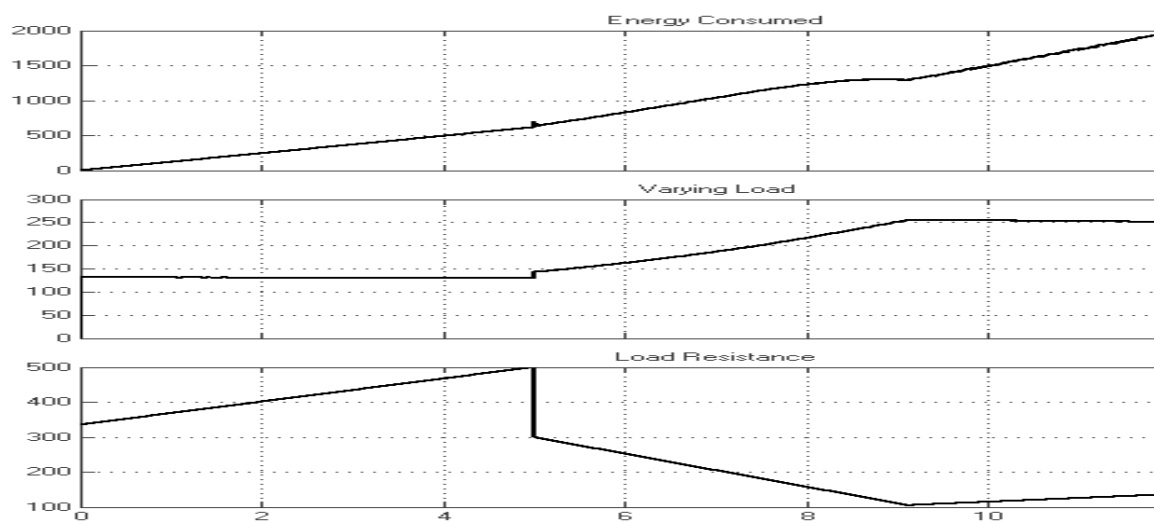


Fig. 9: Measurements under Impedance Load

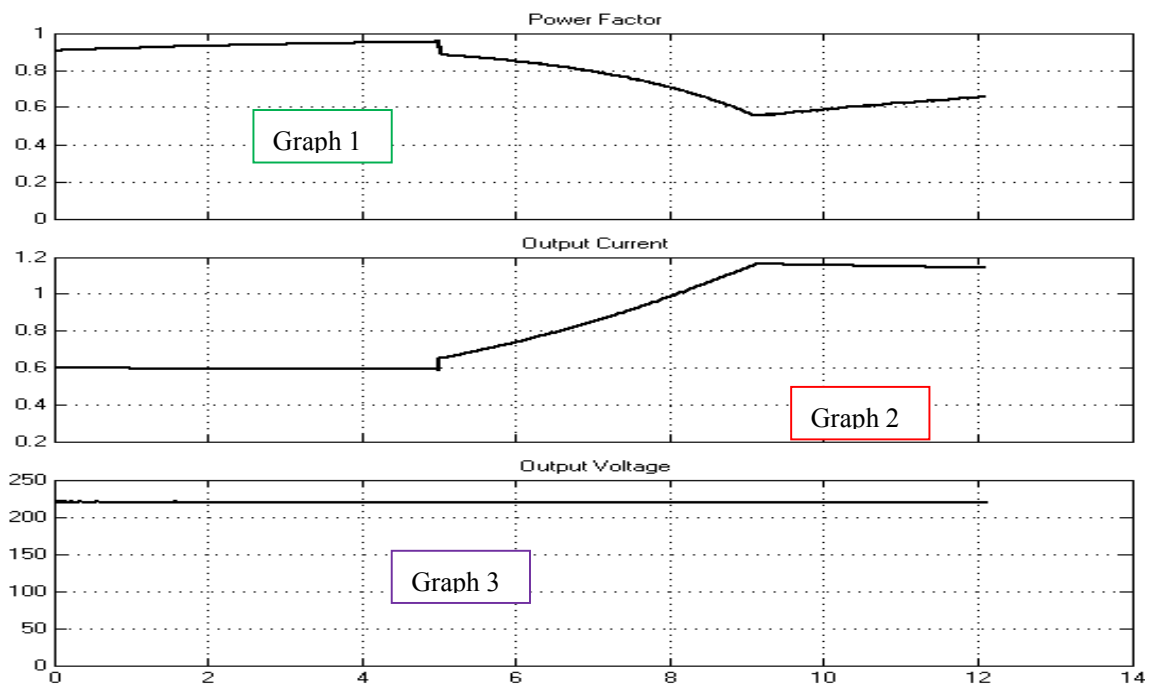


Fig.10: Graphical Display of Measured  $I_o$ ,  $V_o$ , p.f. parameters under Impedance Load

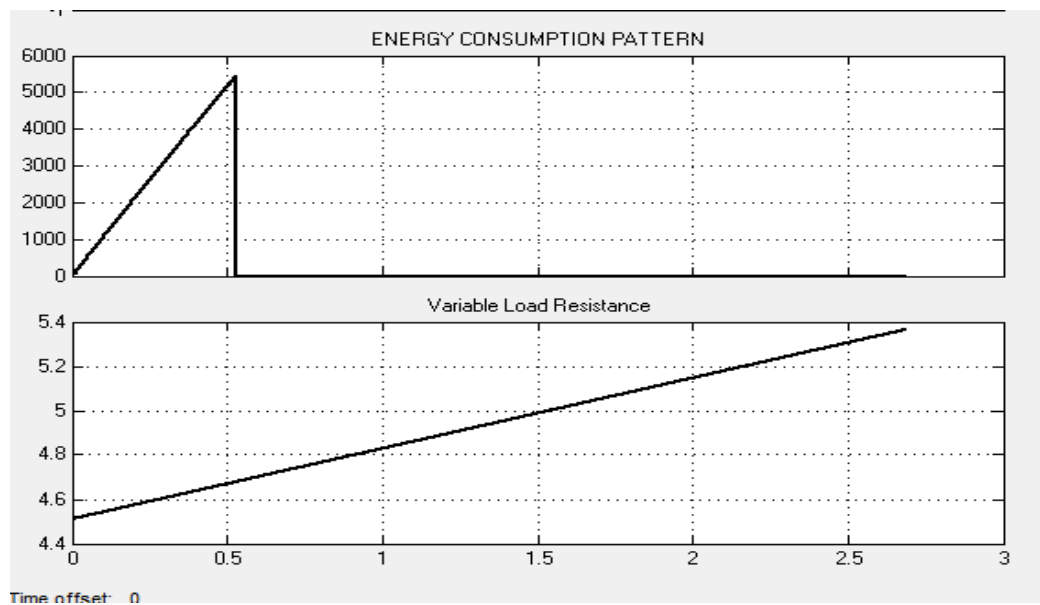


Fig. 11: Energy Consumption for a Load with Variable Resistance.

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