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Design and building a single-phase smart energy meter using Arduino and RF communication system

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Abstract— This paper produces the design and building a system that gives a solution to the measurement of energy and helps the local customers to save the power in an efficient manner. Also, in this paper have been introduced the design, realization, and testing a wireless monitoring system for measuring the energy consumption of electrical devices in the consumer's homes. The system consists of power consumption monitoring systems (smart meter) at customer homes and a control system for remotely reporting and handling the smart meter readings at the power distribution station. The server shows the readings from these meters system by means of a client visual interface continuously. An Arduino kit with current and voltage sensors are used in the meter for measuring the power and RF kit is used and a local server for communication. The client does not need to exert oneself to note their power use so as to control their behavior to decrease their energy usage and costs. The designed smart meter and a mechanical meter are tested in several experiments to indicate the differences in their features.

Index Terms—*Smart meter; mechanical meter; current sensor; RF transceiver; power distribution system.*

I. INTRODUCTION

In a world of rising energy cost human beings and organizations have been started for investigation for an efficient way to minimize their extended electric cost. The appropriate method for decreasing these expenses is to continuously monitor the power that has being expended and from this information, comparing the available choices about how to deal with the electrical devices being controlled [1]. As more home machines and customer uses electricity are introduced, residential energy consumption tends to grow rapidly [2]. A large number of home devices increase the control utilization in two ways: standby power and ordinary control. Those two types of force utilization are relative to the quantity of home devices. Subsequently, the operational cost in homes is additionally expanding. If a person can instantly watching how much power consumes per minute, they might be more careful later on about giving devices a chance to stop working when not required. The project means to give a clear vision of a home's energy use.

The roll-out of smart meters will be the necessary and important step to address the problems of energy consumption in which consumers will be able to provide real-time feedback on the effect of their energy use [3].

The present system of the energy metering system has been planning to be used in Iraq, which uses electromechanical energy meter which is inaccurate and consumes more time and works for collecting the information from users' homes. In developed countries, the conventional electromechanical meters have been replaced by electronic meters to reduce efforts and to improve accuracy in meter reading. Still, the Iraqi power sector faces a serious problem of actual revenue loss of electric power processed is because of energy thefts and network losses as well as the users have another problem is the unreliable traditional billing system because the meter readings are inaccurate and leads to pay large sums of money in excess of the real use [4]. One way through which today's energy problems can be tended under the reduction of energy use in households. The existing observing systems just give review toward the end of the month as kilowatt-hours (KWh) [5].

In this paper, we introduce an Arduino based power meter which objective is to give clients their consumption data that they could benefit to enhance and decrease their electricity consumption. The system was comprised of the ACS712 current sensor, AC-DC adapter with voltage divider, the main Arduino board, the wireless NRF24L01 Fro Module add-on board, 20*4 LCD and the base station computer. The comparison between electromechanical meters and smart meters is discussed in section II; the principles of measurement will be discussed in section III; Design and building of the electric smart power meter is shown in section IV. Section V shows the experimental results. Finally, the conclusion will be in section VI.

II. COMPARISON BETWEEN ELECTROMECHANICAL METERS AND SMART METERS

The operation of Energy Meters is refined by measuring the quick estimations of voltage and current continuously to get the power consumption kilowatt-hours (KWh). Single-phase KWh meters are ordered into two types: Electromechanical meters and Electronic meters [6].

A. Electromechanical meters

An electromechanical induction meter which is shown in Fig.1 counts of how many times the metal disk rotated. The rotation of this disc is proportional to the power passing through the meter. Thus the energy consumption is proportional to the number of revolutions.

Electromechanical meters are extremely unreliable. Anything that expands the delay that the episode roller can bring about a meter to run heavily, resulting in reduced bills. Worn gears, consumption, humidity, dust, or affected by an accidental drop to floor It can cause obstruction of work and result in an electromechanical meter that does not catch the full advantage of the reason for its manufacture [7].



Fig.1. The mechanical meter.

B. Smart meters

The smart meter is used to measure the accurate energy consumption for customers. With a flexible communication module, the meter provides varieties communication media for remote measuring and monitoring. There are two principle sorts of smart meters: Programmed Meter Reading (PMR) which utilize one-way communication and Advanced Metering Infrastructure (AMI) utilize two-way communication to both transmit use data and perform perception and maintenance tasks [8].

III. PRINCIPLES OF MEASUREMENT

Basically, a watt-hour meter is designed to measure energy or power consumed over time.

$$\text{Energy} = \text{Power} * \text{Time}$$

In simple terms, the average power can be calculated by the following equation:

$$W = \frac{1}{T} \int_0^T (v * i) dt$$

Where : v = instantaneous voltage , i = instantaneous current , t = time and T = period . The method used to measure power is taken from the basic definition of power equation. The integration is performed by numerical method , where integration can be replaced by the following summation .

$$W = \frac{1}{N} \sum_{j=1}^N v_j * i_j$$

Means that taken instantaneous values and then divide it by a number of times to get the average power which equals the real power. The system can measure rms voltage and current , and real power. Measuring system can be divided to three stages :

1. Analog signal conditioning

By translating the input current and voltage to the specific range . The ACS712 current sensor used to measure current which have an inner signal condition circuit , and AC/DC adapter used to measure voltage which includes step down transformer to reduce the voltage 220 volt to 24 volt. This range is outside the analog input voltage of the microcontroller so it should be reduced to 0-5V range, this is done by the voltage divider .

2. Analog to Digital convertor (ADC)

The analog to digital convertors in Arduino converts the input signal from an analogue signal to a digital signal (zero or one logical) .The digital analogue converter (A / D) is used to cut and convert digital signals into digital information for several purposes in control and modification.

3. Digital measurements

The power equation is used to calculate the power consumed using the microcontroller (Arduino).

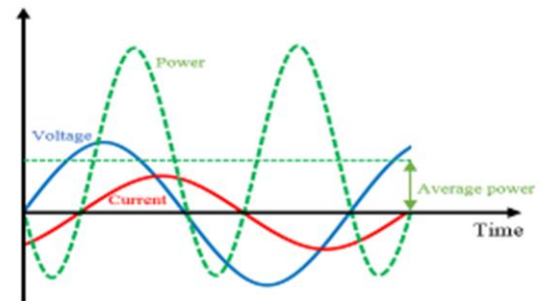


Fig.2. Power waveform

IV. DESIGN AND BUILDING AN ELECTRONIC SMART METER

Smart Meters are electronic estimation devices used for collecting client data and transmitting their electricity use to the monitoring systems. Detecting current and voltage and transmission these quantities into the outline of the smart meter. Smart meters gives a course to reduce spending money and save it properly as well as continuous estimating, computerized information gathering and avoiding human errors because of manual readings which would at last lessen work costs. This takes into account the upkeep events for more productive and dependability [9]. The system proposed comprises of two fundamental parts:

- i) Hardware design
- ii) Software design

The execution of a fundamental watt-hour meter includes four hardware modules as shown in Fig.3. These modules represent by the voltage measurement module, the current measurement module, the wireless communication module and the monitoring module.

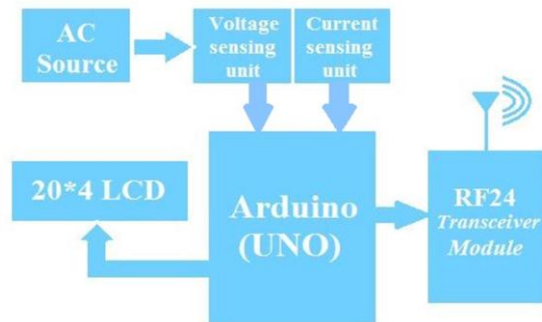


Fig. 3: Block diagram of the transmitter system

A. Voltage measurement module

To measure 220V AC, step down this voltage to AC voltage whose peak value should be less than 5V to be suitable with the voltage of the Analog to digital converter of the microcontroller. Also, this AC voltage must convert

to DC voltage using bridge rectifier [10]. In this module, we used AC\DC voltage adapter for adapting the voltage to the microcontroller as shown in Fig. 4 (voltage measurement module). The analog voltage to be measured is connected with one of the ports of the microcontroller (A1). The microcontroller (Arduino UNO) contains a built-in ADC which changes the voltage to a computerized esteem.

The microcontroller is programmed to change over this advanced esteem again to the estimation of connected voltage. The esteem is then shown through an LCD show. ADC is determined in a number of checks. We have intended for 1024 numbers with 10mV/bit determination [11].

A. Current measurement module

The microcontroller can only sense the voltage on the analog pins, there are many ways to convert current to voltage. The choice has been used in I-V conversion is the Hall Effect current sensor (ACS712) that is connected to the analog input (Ao) of Arduino as shown in Fig. 4 (current measurement module).

In-line Hall Effect sensor (Fig.5) capture the AC current furthermore, couple it with an inside aligned Hall Effect component. This strategy is popular and more exact. The high voltage is electrically separate from the low voltage inside the sensor and that giving an electrical separation [12].

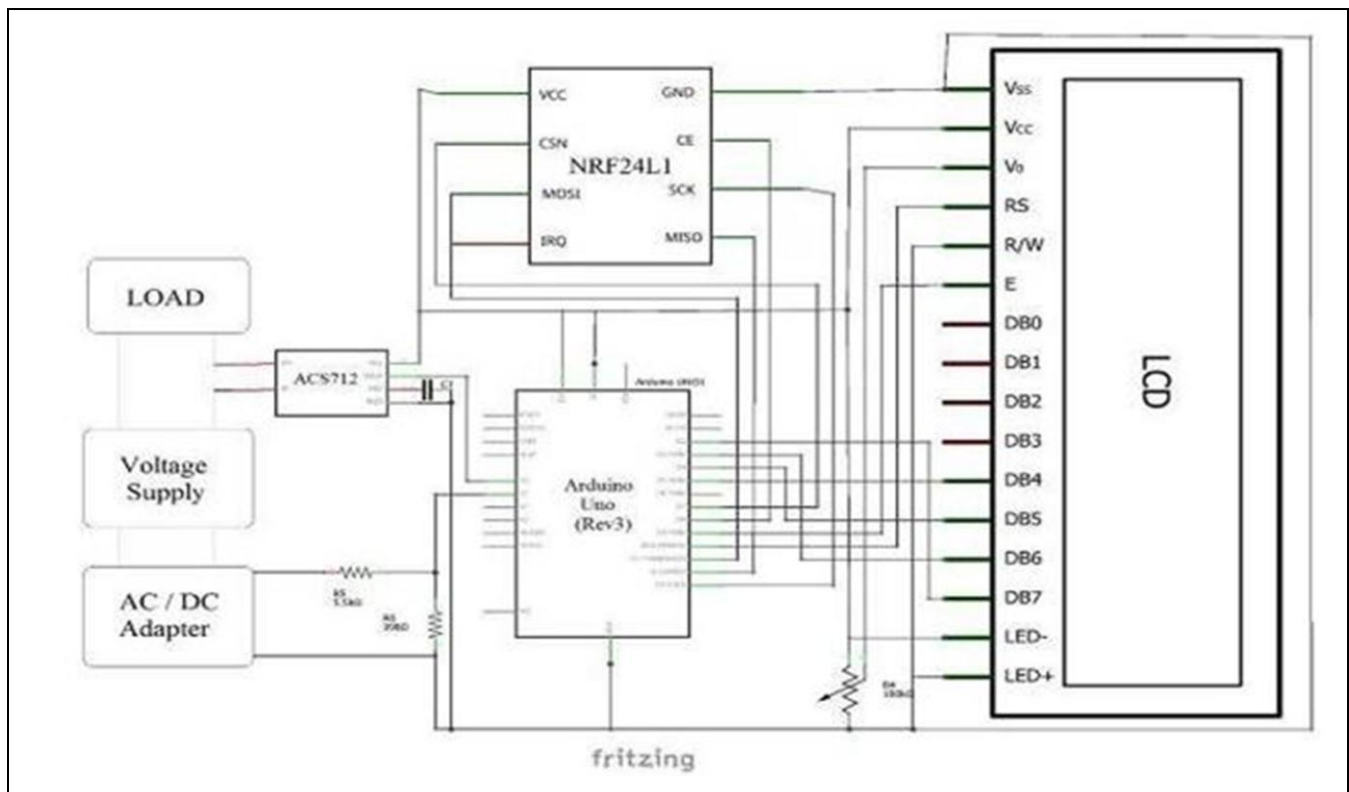


Fig. 4. The schematic diagram of electrical smart meter.

B. The wireless communication module

Arduino UNO kit does not have any wireless communication module in stock. In order to support wireless data transmission we prefer NRF24L01 RF Transceiver Module (Fig. 6) to work with the Arduino. This RF transceiver is known for its ease of use, small energy consumption, and extremely low cost. NRF24L01 supports 2.4 GHz wireless data transmission with low energy consumption [13].

C. Monitoring module

There are two monitoring systems are used in this system: one in the transmission side (smart meter side) which are represented by Liquid crystal display (LCD) as shown in Fig. 4, while in the electricity monitoring station there is the main computer LCD which show received information using Visual Basics program. Liquid crystal displays have an assortment of connections that can supply the client with the coveted data going from a basic clock to perusing the power consumption. The liquid crystal display is energy effective and outperforms different models. These LCDs are made thin which permits a great deal more space for alternate parts of the device to fit every one of the segments together to preserve energy [14].

D. Receiving unit

This module is made out of an easy to use serial order set. It permits dependable and directed correspondence between microcontrollers, PCs, installed systems and so on. Basically with any system with a serial port. 2.4GHz RF24 module pack up both point and multipoint communication. In this way, it is conceivable to speak with a few remote units connected with various machines from a remote checking unit. Special RF24 modules' setups can be used to meet different plan prerequisites, for example, remove, spending plan, arrange topology and so on. Block diagram of the receiver system is shown in Fig.7.



Fig.7: Block diagram of the receiver system

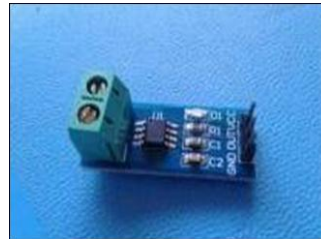


Fig.5. ACS712 current sensor



Fig.6. NRF24L01 RF Transceiver

F. Software design

The software part of the project represents the programs written on the Arduino board and the base station PC. Current and voltage was measured from the two current conveying wires into the principle control board, tested by the Arduino board and sent as a UDP packet over the NRF24L01 Fro Module system to the base station PC, and after that show current, voltage and power consumption to the client throw LCD. Figure 8 shows the energy monitoring software's flow chart. This software is written using C-Language for Arduino. The UDP packet that has been sent by the transmitting unit over the NRF24L01 module system is received by the base receiving unit. The receiving unit then parsed the packet, and computerized transformation into current information to the power checking base station (PC) using C-Language for Arduino placed at the receiver side and Visual Basic Language for base station PC. Figure 9 shows the receiver software's flowchart.



Fig. 8. Flow chart for the software of the transmitting system

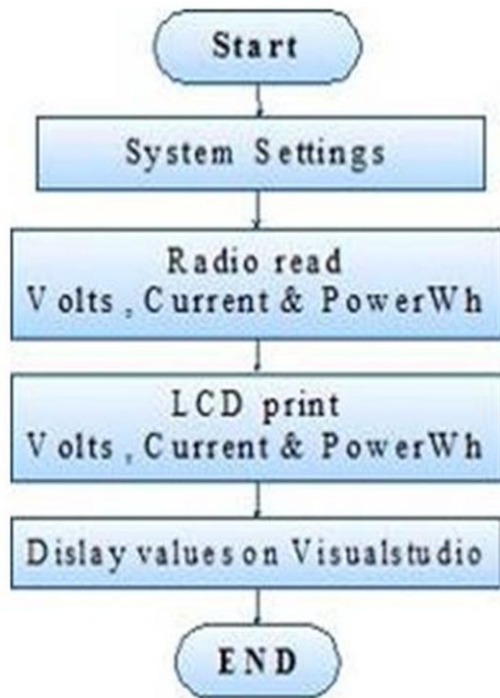


Fig. 9. Flow chart for the software of the receiving system

V. EXPERIMENTAL RESULTS

Several experiments have been accomplished keeping in mind the end goal to imitate the operation of remote power

system. Figure 10 shows the photograph for the first experiment for measuring the power using the smart power meter. The measurements begin through the AC adapter as isolate and step-down stage. Then a potential divider step which damping voltage supply to the low level voltage by utilizing voltage divider as appeared as a part of Fig. 4 where R1 and R2 are chosen (5.5 K Ω and 998 Ω separately) to attenuate (23.48 to 3.562 V) supply voltage. The load current has been measured by using the ACS712 current sensor which converts current to the voltage suitable to the microcontroller. In microcontroller, the power consumption has been evaluated. The smart meter is connected to RF24 Transceiver, which sends the measurements to the base station. At the base station, the data has been gotten. In this venture, the ID of a client has been chosen same as RF24 Transceiver ID which communicates to the source address of RF24 Transceiver. The electric power estimation data has been sent from END devices to the coordinator by frames incorporates source address. This information has been analyzed and displayed on the base station screen. System software has been intended to screen the electric power parameter of clients.

The second experiment is implemented using the mechanical meter as shown in Fig. 11. In this experiment, we used an auto transformer and thermal resistor as load and single phase mechanical meter.

The power measurements in both of the above experiments are repeated for 12 hours to give a suitable comparison between the smart and mechanical meters.

Fig. 12 shows the results of comparison between the smart and mechanical meters with respect to actual power spent in load. From these reading, we found that the smart meter has an accurate reading with respect to the mechanical meter.

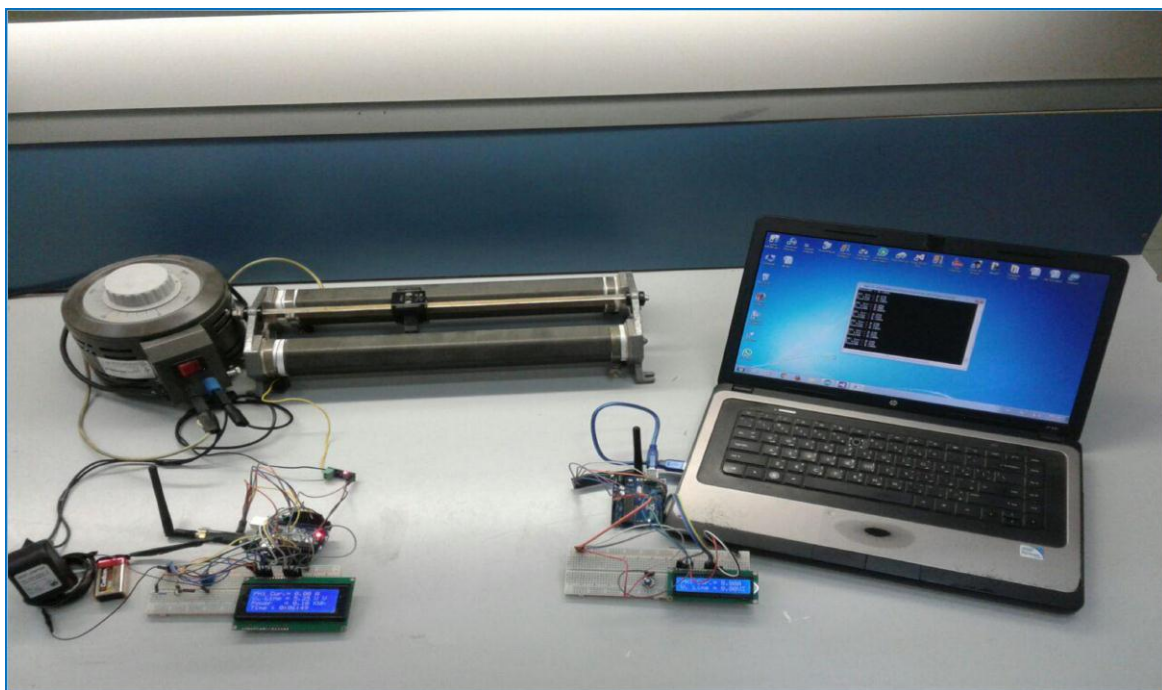


Fig. 10. First experiment : Smart power meter

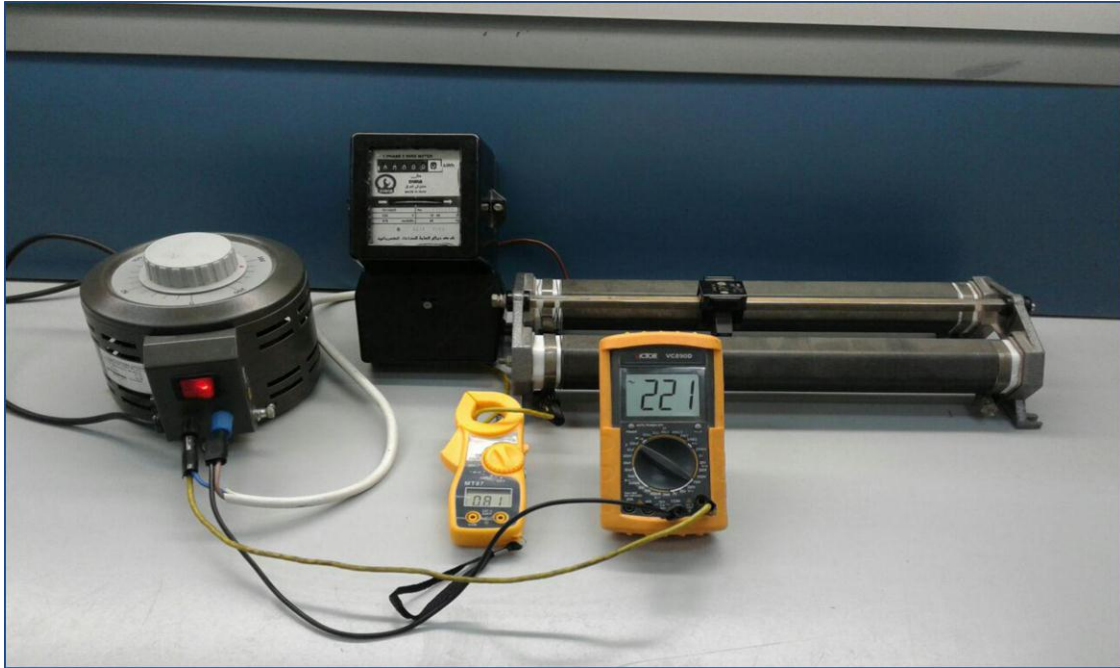


Fig. 11. Second experiment : Mechanical power meter

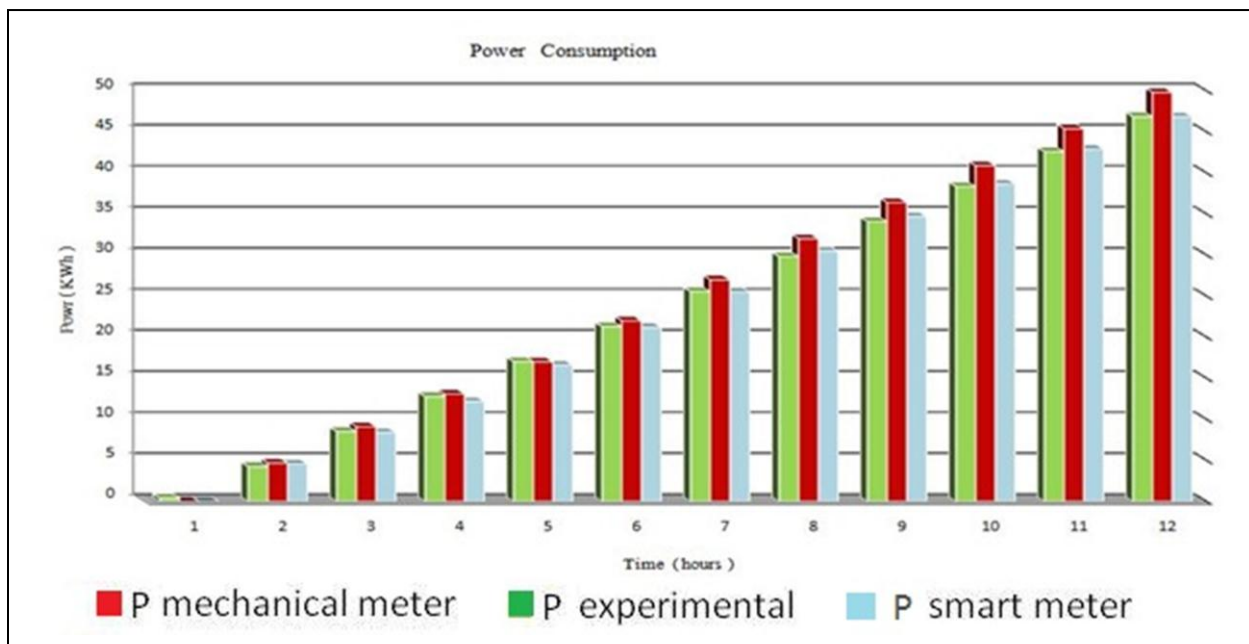


Fig. 12. Comparison between actual, smart and mechanical meter readings.

TABEL 1. Experimental results

Time (hours)	1	2	3	4	5	6	7	8	9	10	11	12
<i>P experimental (KWh)</i>	0.426	4.26	8.52	12.78	17.04	21.299	25.56	29.82	34.07	38.34	42.598	46.857
<i>P mechanical meter(KWh)</i>	0	4.7	9.1	13.1	17	22	27	32	36.4	40.9	45.4	49.8
<i>P smart mete (KWh)r</i>	0	4.57	8.4	12.17	16.6	21.2	25.51	30.5	34.69	38.65	42.9	46.85

VI. CONCLUSIONS

In this paper, a smart energy meter system is designed and built using Arduino UNO microcontroller with current and voltage sensors. The measuring Kilowatt hours is transmitted to the base station using two RF NRF24L01 transceiver modules in both the smart meter and the base station. The smart meter is used to replace the mechanical energy meter that has several advantages over the mechanical one. Also, smart meter has the ability to give us the voltage and current reading at each instance of time. Also, we can use the smart meter for producing another reading by programming its microcontroller.

By comparison both meters we found our designed meter has reading approximately equal to the actual reading as shown in table 1 . The average percentage error of the smart meter is 1.86% while the mechanical meter error was 5.054%.

For future work we suggest to expand the smart meter to work with three phase system and to replace the display module with another has the ability to display the results as a graphics form.

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