Design of Smart Socket for Power Optimization in Home Energy Management System

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Abstract—Home Energy Management System (HEMS) plays a crucial role in the measurement and optimization of power consumption at the consumer premises level. This work emphasis on design and development of smart socket with wireless capability, which can estimate different power parameters and accumulate the real time power consumption data of individual home appliances. A ZigBee transmitter and receiver node aids for the data communication in HEMS setup, which forms the Home Area Network(HAN). Real time data gathered at the central node can be used to prioritize and schedule the appliances. The HEMS set up can be used to create the dataset for home appliances, further dataset can be used for load disaggregation.

Keywords—Home Energy management System; Smart meter; Smart Socket; ZigBee;

I. INTRODUCTION

Deregulation in Power sector gained a significant change in the development, which facilitated industrial and commercial users to produce electricity at the cheaper price and even selling it to the clients. There are so many factors that are associated with Deregulation in power sector such as Privatization, reliable & cheap, privatization, customer focus and innovations [1].

Distribution Automation System plays a vital role in the smart grid environment, which can save time by performing sequence of operation repeatedly at the faster rate. Distribution System Automation plays a key role in outage management and fault recovery of the system as well [2]. There are several benefits of Distribution Automation System in terms of Operational Maintenance, financial and customer related benefits.

Distribution automation system is classified into two different categories as Distribution Substation & Feeder and consumer location automation. Distribution substation automation includes supervisory control of circuit breakers, load tap changers (LTC's), regulators, recloser's, switches and capacitor banks. Consumer automation includes reading of the meter power consumption data remotely, service connect/disconnect and managing the consumer loads [2].

Reliability of electric distribution system is very much essential for both utilities and consumers. Most power outages are caused due to environmental hazardous condition and overhead of power lines. Modernisation in the smart grid makes use of bidirectional smart meters, remote control switches and Intelligent Electronic Devices(IED's), which gathers large amount of data and provides sufficient information to monitor system operation in near real time [3].

Innovation in the Renewable Energy Sources(RES) is observed to be remarkable in the recent decades. Shortage of conventional fuel based energy is the main motivation factor for deep penetration of RES with the smart grid systems [4].

In order to reduce the power consumption at the consumer premises level, HEMS plays an essential role. Efficient Energy management with the home appliance is a key feature of HEMS set-up. Context aware and user activity information can be further used to optimize the energy usage in HEMS. The main goal of HEMS is to reduce the energy consumption considering the user comfort level, to achieve this, monitoring of the energy consumption is needed along with the appliance management strategies.

This paper emphasis on proposed work of Home energy management system with smart socket capability. The contribution of this work are detailed in the sections below:

First, literature survey of related work is discussed to know the present state of the art in this area. In the following section details of the proposed work is presented considering the Energy optimization technique in home environment system. Further section elaborates on simulation of energy meter with different power quality parameters in proteus environment. The experimental work is carried out for the same using Arduino-Uno ATMega328 micro-controller along with LEM LA-55P hall effect based current senor and testing of the serial communication is done with XBee series-2 modules. Finally, future scope of the work and conclusion of the work is described.

II. LITERATURE SURVEY

A smart socket is used to communicate with an individual appliance in the home environment from a Central Gateway node. Smart Socket mainly consist of a micro-controller unit and sensors for measuring power consumption, a ZigBee module for communication and a Relay unit for switching the power supply to the appliances. Display unit assembled with smart socket displays the power consumption of an individual appliance. The power consumption data from individual appliance is sent to the central Gateway, where data is processed to take a suitable decision depending on the constraints of the available power. The features of a Smart Socket system include Appliance control, Monitoring and fetching the Data via XBee Communication module.

Song et al. proposed a hybrid architecture which consist of three different layers such as mote layer, server layer and client layer. In the proposed system authors have designed a mobile node called as Racemote, which has the capability to sense and process the indoor environmental information and configure accordingly. Thus, home monitoring system is built using hybrid sensor network, with suitable network route formation and event tracking capability [5].

Suh et al. proposed an intelligent home automation system with ubiquitous home network feature. Sensors and actuators are used to monitor and control the home appliance status efficiently with an integrated sensed information from the active sensor network. The developed system has the sensing components to gather the information from deployed home sensor environment and Decision components to processes and activate the Service Components such as home automation or home security. Interaction components are used to communicate between sink and central network node with communication components, Finally Control components are used to control the appliance condition [6].

Pan *et al*. proposed a decision control algorithm model based on the user profile and illumination of the light. The system considers the two devices, Whole lighting and the Local lighting for the background light and the light intensity consideration respectively. Hence the model considers the illumination of light according to the different user profile activities and thus reduces the power consumption and satisfy the user requirement using a closed loop system [7].

Gill et al. proposed a home automation system with central home Gateway which facilitates for the interoperability between ZigBee and Wi-Fi network. Experimental setup is developed to check the co-existence of ZigBee and Wi-Fi network performance. Authors also tries to identify the problem encountered for the slow adoption of home automation system [8].

Han et al. proposed an energy optimization solution for Home Energy Management System (HEMS) employing a remote tracking and ZigBee technology to minimize the standby power utilization. The proposed system includes home server, ZigBee hub, dimming light intensity and power outlets interfaced with ZigBee communication and control buttons. Power outlets has the facility to measure power consumption of the home appliance connected to it. In the proposed system, if a particular appliance is consuming power below a threshold value then immediately AC power is turned off with provided delay time. The proposed system also has the flexibility of appliance portability to different power outlets within the deployed environment of ZigBee coverage by changing the identity of the appliance in the User interface. But this system may not be suitable for some appliance like PC where if it is turned off directly then some useful data may be lost [9].

Real-time household load appliance monitoring and scheduling of the home appliances based on Dynamic load priority is achieved based on the availability of Renewable Sources. Home appliances are classified into two different categories based on Real time energy consumption and Non-Real time energy consumption, further Non-Real time energy consumption appliances are classified into periodic and non-periodic type. As Real time energy consumption appliances cannot be scheduled, it is serviced immediately as and when required. Non-Real time energy consumption appliances are scheduled and assigned with dynamic priority. Authors proposed a real time Household Load Scheduling Algorithm to schedule the appliances based on the output of real time Renewable Energy sources. In this work Integration of Renewable Energy with Battery State of Charge has not been addressed [10].

Jinsung Byun et al. proposed an intelligent cloud home energy management system, which assigns dynamic priorities to home appliances and considers the current status of appliance.

Renewable energy availability is considered for appliance scheduling. Household appliances are classified according to operation characteristic's such as Type-A, Type-B and Type-C based on resident activity pattern, environmental factor and state of embedded battery respectively. Since operation of Type-A appliances are dependent on user activity, these appliances cannot be delayed from its operation. Type-B appliances are scheduled considering the environmental conditions and comparing with threshold value set by the user such as temperature, lighting condition and Humidity etc. Type-C appliances are battery dependent and hence these appliances can be scheduled depending on the condition of battery status. Experimental set up has been implemented and verified by the authors successfully [11].

D. Brunelli et al. propose a complex system to save energy for a residential context with renewable resources and Hybrid Electrical Storage. Proposed System has different scheduling options towards Generation side and Demand side as well, it can choose among alternative energy sources and assign the priority with load shedding [12].

G. R. Liu et al. proposed the integration of Renewable Power Systems (RPSs) with Conventional Power Systems (CPSs) aids for cost effective solution to electricity usages and Home Appliances. In this work Authors considers for the Charging Process of Renewable Power Systems along with Conventional Power System. Authors proposed threshold policy in a multi-dimensional policy, i.e., for power demands of different appliances, different thresholds are used to determine whether the power demands should be served by the CPS or RPS [13].

J. A. Jenifer et al. proposed smart home automation system along with the sensors and actuators, which is modelled using LabVIEW tool. The system is designed to monitor the status of the appliances and personal computer is used to control the status of appliance [16].

In comparison to the existing work, this work focuses on designing a HEMS setup to acquire the different power parameters at steady state and the transient states of a load appliances considering the low cost design. Further HEMS setup is used to manage the alternate generation of sources for minimal usage of energy from grid and efficient utilization of renewable energy source. In the home premises, load scheduling and priority assignment of load can be achieved. Further, aggregated readings from smart and sub-meters can be used for Load disaggregation technique such as Non-Intrusive Load Monitoring(NILM) to control and manage the appliances effectively.

III. PROPOSED HOME ENERGY MANAGEMENT SYSTEM MODEL.

The architecture of power negotiator using ZigBee as a communication interface is as shown in Figure 1 below, where in each appliance is connected to an additional interface called smart socket and not directly to the power socket. When the user wants to turn on the appliance, user has to use pushbutton on Smart Socket. Smart socket sends out a request to the master, master receives the requests from the smart socket and runs a power negotiation algorithm to figure out a power budget and then based on the result of power negotiation algorithm, master approves or rejects the request. On approval, appliance gets turned on and smart socket starts measuring the energy consumed by the appliance till the appliance is turned off or pre-empted by

master and further updates the master with the total energy consumed by the appliance.
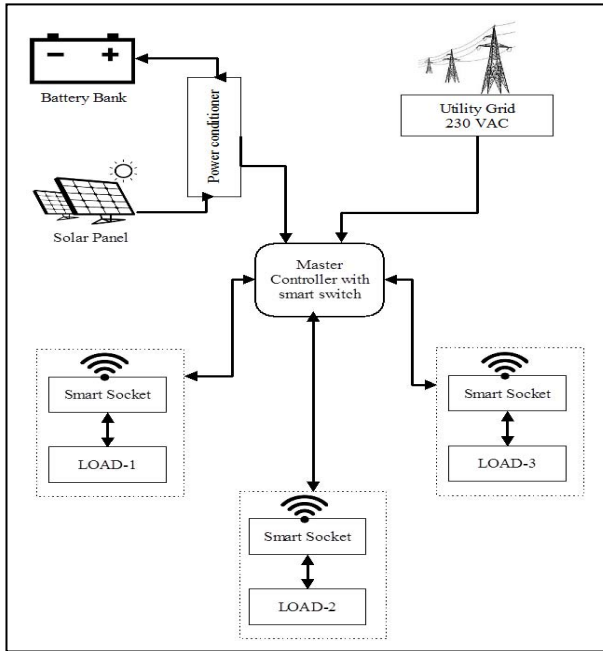

Fig.1 Proposed Home Energy Management System Model.

Smart socket is an intelligent replacement for a general power socket, which encloses a communication interface, current sensor, MCU unit and a switching circuit. The roles of smart socket are as follows,

1. Measure Instantaneous power drawn by appliance connected to it.

2. Compute energy consumed by the appliance.

3. Runs requisition algorithm of power negotiation and takes decision of turning on \ turning off the appliance.

IV. EXPERIMENTAL WORK CARRIED OUT.

In this work first simulation part is done to check the working of the energy meter design. Further, hardware experimental design of the energy meter is carried out.

A. Simulation of Energy meter using Proteus Enviornment

The Simulation of Single Phase Energy Meter is carried out using Proteus software, the simulation environment is as shown below in Figure 2. The simulation circuit consist of a differential amplifier circuit to scale down the supply voltage, a DC offset circuit to make the signal positive going. Arduino IDE is added to the Proteus-8 simulation library to simulate this model, code is compiled in the Arduino IDE and HEX file is generated. The generated HEX file is uploaded to the Arduino prototype in the Proteus simulation environment. The Analog pin of Controller has a 10-bit in-built ADC to digitize the analog signal. Further the fetched voltage signals are manipulated to get the desired power quality parameters.
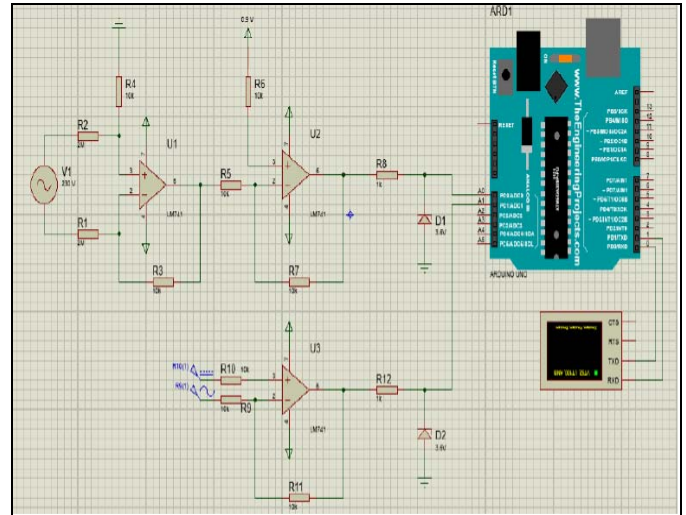

Fig.2 Simulation of Energy Meter using Proteus-8 Environment.

1) Voltage Measurment

In this work, 230V RMS has to be measured since directly 230V input cannot be applied to microcontroller Unit. Because microcontrollers can only read voltages from 0-5 V. If input voltage to the microcontroller exceeds 5 V it may damage the internal circuitry. So there comes the role of voltage scaling.

The Measured Grid Voltage is observed to be 360 V_{p-p} as shown in Figure 3, differential amplifier circuit is used to Scale down the voltage by choosing appropriate values of feedback resistance and the input. Further a DC offset voltage can be added accordingly to read the voltage in the microcontroller unit as shown in Figure 4.
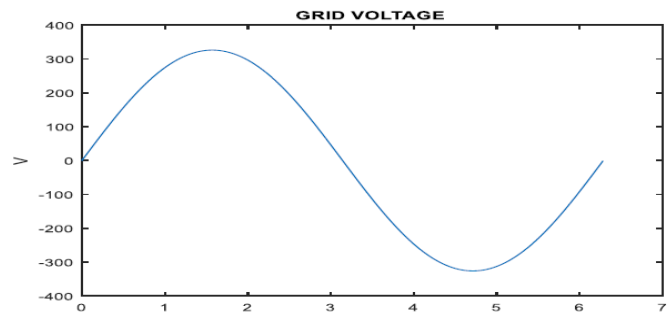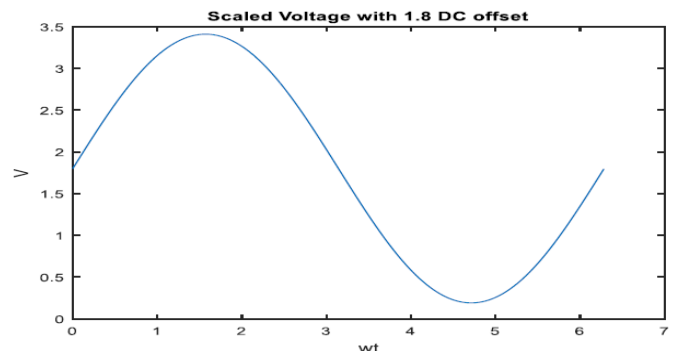

Fig.3 Waveform showing the grid Voltage to me measured

Fig.4 waveform showing scaled down voltage with DC offset

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2) Current measurement using ACS712T

Line current is first downsized using ACS712T 30A current sensor module. Since the sensor output will have a DC offset of 2.5 V, a separate circuit for offset is not required. The sensitivity of the sensor is 66 mV/A. For example, if 2 A line current flows, the output will be 132 mV peak to peak sine wave with 2.5 V DC offset. The current sensor module is connected in series with a load and the proportional signal for a load current is given by.

$$V_{out} = K * I_{in} \qquad (1)$$

Where 'K' is found out from the ACS712 data sheet to be 66 mV/A.

B. Development of Energy Meter experimental set-up

The Hardware Circuit Designed for Energy Meter is Shown in Figure 5. A Power supply unit of $\pm$ 12 V DC is designed using LM7812 & LM7912 IC's to provide power DC power op-amps of signal conditioning circuit. A Rheostat is used as a load with 15 A and 4.3 Ω ratings. The Serial Monitor Console Window of Arduino Uno values are tabulated, as shown in Table I which displays the different parameters obtained by manipulation Voltage and Instantaneous Current Signals such as Instantaneous RMS Voltage(V$_{rms}$), RMS Current(I$_{rms}$), Apparent Power, Average Power, Power Factor, Frequency, Voltage Variation, Total Harmonic Distortion (THD) and Energy Consumption.

The specification of the Arduino Uno Micro-Controller unit is listed below in Table-I.

TABLE I
Specification of Arduino Uno Micro-Controller Unit

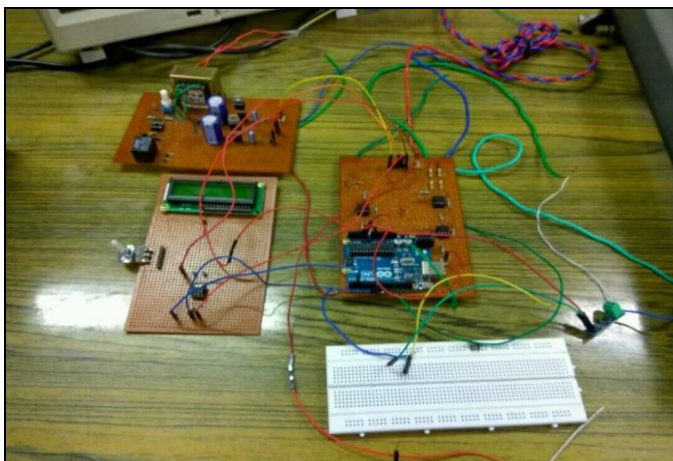| Microcontroller	ATmega328
Operating Voltage	5 V
Input Voltage (recommended)	7-12 V
Input Voltage (limits)	6-20 V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3 V Pin	50 mA
Flash Memory	32 KB of which 0.5 KB used by bootloader
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

Fig.5 Experimental Set up of Energy Meter.

Calculations of different electrical parameters of a load:

1. Instantaneous Voltage(v$_{inst}$) & Current(i$_{inst}$)

The signal conditioning is done to the actual Voltage and Current signals before it could be processed with the Microcontroller unit. ATMEGA328 Arduino UNO microcontroller unit kit is used to read the analog values from the circuit, which is sampled using 10-bit ADC of the kit. The maximum sampling rate depends on the resolution of ADC, each individual sampled signal gives the instantaneous values of Voltage and Current readings.

2. Calculating the Real Power(P)

The instantaneous values of Voltage and Current readings are used to estimate the real power of the circuit. Product of instantaneous Voltage and Current is calculated to find instantaneous power(p_{inst}); sum of instantaneous power is calculated by successive addition of instantaneous values and finally sum of instantaneous power is divided by no.of samples to get the real Power consumption. For 'n' no.of samples calculation of real power is shown in equation-2.

$$p_{inst}(n) = v_{inst}(n) * i_{inst}(n)$$

$$\sum p_{inst}(n) = \sum p_{inst}(n-1) + p_{inst}(n)$$

$$P = \frac{\sum p_{inst}(n)}{n} \qquad (2)$$

where 'P' is the real power.

3. Root-Mean-Square (RMS) Voltage & Current

For the 'n' no.of samples, the successive sum of the squared voltages from the instantaneous product values of voltage is calculated and divided by the 'n' no.of samples to get the mean and RMS value of the Voltage as given by equation-3.

For 'n' no.of samples

$$V_{rms} = \sqrt{\frac{\sum v^2}{n}} \qquad (3)$$

Similarly, I$_{rms}$ is given by equation-4,

$$I_{rms} = \sqrt{\frac{\sum i^2}{n}} \qquad (4)$$

4. Apparent Power(S)

The product of RMS Voltage and RMS Current values gives the Apparent power of the load, which is given by equation-5.

$$S = V_{rms} * I_{rms} \qquad (5)$$

5. Power Factor(pf)

The value of real power is divided by the apparent power to measure power factor parameter, which is given by equation-6.

$$Pf = \frac{P}{S} \qquad (6)$$

Where, 'P' denotes the real power & 'S' denotes apparent power.

6. Total Harmonic Distortion(THD).

Total harmonic distortion is the summation of all harmonic components of the Voltage or Current waveform w.r.t the fundamental components of Voltage or Current Waveform. Calculation of THD is shown in equation-7.

$$THD = \frac{\sqrt{V_2^2 + V_2^2 + V_2^2 + ...V_n^2}}{V_1} * 100\% \qquad (7)$$

Where, V_1 is the RMS value of fundamental frequency component of voltage waveform, V_2, V_3, …V_n are the RMS values of harmonic components of voltage waveform.

7. Energy (E).

Energy of an appliance is calculated as product of power and the time of power consumption, which is given by equation-8.

$$E = P * t \qquad (8)$$

Where, "P" is the power consumed & "t" denotes time of power consumption by the load.

TABLE II
Experimental energy parameters from Arduino console window

Power Parameters	Power Parameters Reading		
	Sample-I	Sample-II	Sample-III
V$_{rms}$ (V)	222.7	222.73	220.96
I$_{rms}$ (A)	0.59	0.59	0.59
Apparent power (W)	130.80	130.37	129.96
Average Power (W)	130.00	130.37	129.96
Power factor	1.00	1.00	1.00
Frequency(Hz)	49.50	49.49	49.50
Voltage Variation	-3.32	-3.16	-3.93
THD	1.47	1.58	0.93
Energy(Wh)	48.52	48.56	48.61

C. The XBee ZigBee Module Communication.

XBee modules are embedded solutions providing wireless end-point connectivity to devices. These modules use the IEEE 802.15.4 networking protocol for fast point-to-multipoint or peer-to-peer networking [14]. They are designed for high-throughput applications requiring low latency and predictable communication timing. XBee uses the Zigbee standard and adds to it and wraps it up in their own neat little package. This section explains the wireless transmission of the data read from the Arduino using the XBee module and also the necessary setup required. The version of the XBee module that is being used here is the XB24 – ZWIT 007 which is commonly called as the XBee series-2 operating on the Zigbee protocol [15].

The experimental work makes use of two identical XBee modules, one of which is configured as the router to send information and connected to the Arduino and the other configured as the coordinator to receive this information and connected to the computer. It is also necessary to mention here that for connecting the XBee modules to the Arduino and to the computer, XBee Adapter and the XBee USB Explorer are required respectively. There are a number of

manufacturers of the XBee adapters and XBee explorers in the market and anyone version would suffice.

The configuration software needed is the XCTU developed by Digi International, the manufacturers of the XBee RF modules.The Configuration of XBee modules is shown in Figure-6, XBee adapters are used to configure the module Using XCTU software in the PC. Reset mode is recommended before Switching configuration from coordinator to Router or Vice versa.
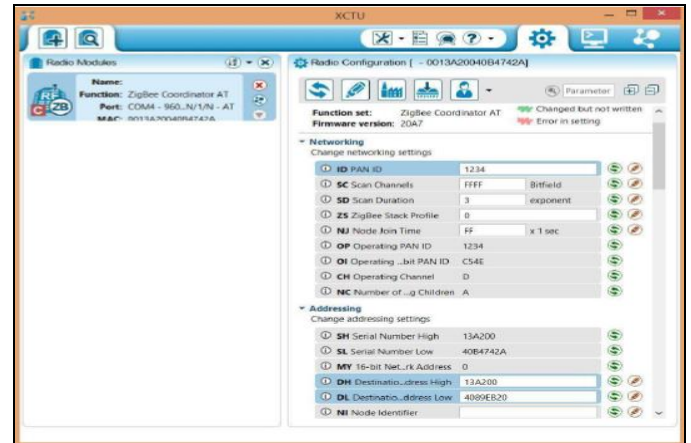

Fig.6 XBee Configuring in Router mode

To begin with the point to point communication of the XBee module, One of the XBee module should be Configured as Co-ordinator Which acts as Transmitter in this Context and Other XBee module is Configured as Router, which acts as a Receiver module in this case. The output in the serial console window of XCTU software is as shown in the Figure-7,the red characters shows the recived data from the transmitter end which is in hexadecimal equivalent format and sent data is represented in blue colored character.Thus,Data has been communicated between two XBee modules successfully.
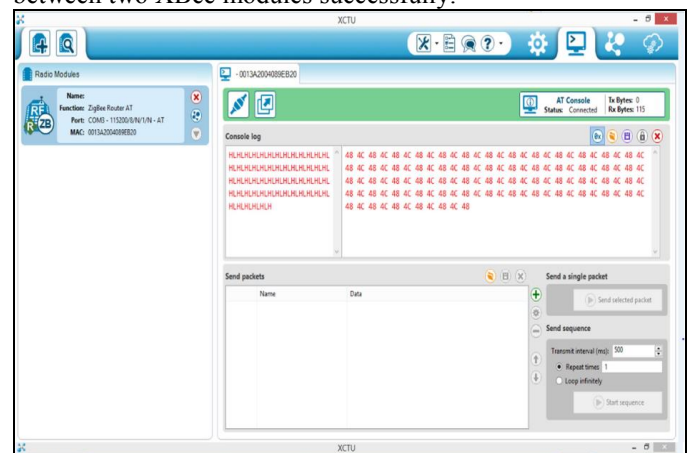

Fig. 7 Testing the Serial Connection

V. CONCLUSION & FUTURE WORK.

This work focuses on Development of Smart Socket for Home Energy Management System, Energy meter is designed to measure the different electrical parameters such as Power factor, Average Power, Apparent power, Total Harmonic Distortion(THD) and Energy Consumed. Following this, communication has been established between the identical XBee modules with serial monitor communication. Further Energy Meter is assembled with the XBee modules to build Smart Socket unit. Future work

emphasis on assigning priority to an individual appliance and scheduling the appliances considering the peak usage and power budget.

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