Implementation of Smart Meter and Data Transmission over Power Line Channel

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Abstract: Transmitting and receiving the data through smart meters (SMs) has now a mandatory part of next generation power system, smart grid. Data Transmission through power lines is now becoming a key technology for smart metering in smart grid communication as well as home automation, Networking and Data Transmission. The idea behind the research is to develop a less complex smart meter through which we can transmit or receive data on existing power lines. The smart meter consists of, from input to output, a digital energy meter, a modem, a transceiver, and a two-way coupling circuit. At receiving end consist of, a two-way coupling circuit, a transceiver, a modem, a control unit with digital display. The main objective of this research is to design an efficient, less complex, and small sized digital energy meter with high data rate PLC modem included harmonized coupling circuit for Advanced Metering Infrastructure (AMI) application in smart grid communications. In this article, we present a research work on power line communication through implementation of the smart meter and transmission of data over power line. Practical implementation and results have shown that the designed modem has the capability to handle huge data of SM, at low complexity and in small package.

Keywords: Energy conservation, energy efficient, smart grid, advanced metering.

I. INTRODUCTION

As the use of electricity increases, electricity supply companies are expanding their networks of cabling. This is to ensure that every consumer is easily accessed not only to energy, also information about usage and pricing. This is the concept of Advanced Metering Infrastructure (AMI) application in smart grid [i]. Earlier, power supply companies were facing difficulties to record customer usage data accurately as they needed manual labor who physically conducted periodic visits to the consumers' premises and record usage data manually. One example is, the interval meter, an energy meter which used to records usage of electricity over short intervals of time: typically, every half hour. But in interval meter needs labors who must visit consumer premises for record the reading of their energy meters. In this entire process the meter readings or data acquired manually can be incorrect, or based on personal benefits, while also there is an also the chance of receiving of data late for billing purposes. To solve this problem researcher suggested the use of smart meters which are capable to send real time power consumption data to back to the supplier. For smart metering there are many communication protocols which designers have been used to communicate between meters and the supplier like ETHERNET, GSM, CDMA and UTMS but all these techniques are costly because all these technologies need extra networking infrastructure specially for under privilege areas where absence of mobile networks and internet connection [ii].

The Smart meter is an advance version of interval metering technology which allows remote communication between electricity supplier and consumer in real time. By smart metering as it is based on real time monitoring, Supplier Company can see the usage of electricity on real time, by smart metering they can analyzed the total load of a house on peak or low load time. Smart metering is also a part of the smart grid system. As in smart grids there are many sub power plants and generation plants are connected which can simultaneously supply their power to all networks connected to a single grid. Smart meters also reduce the need of labor to visit consumer sites to note readings. Smart meters used different ways of communication which include telephone, wireless, fiber cable, and power line communications. All methods of communication have their own advantages or disadvantages [iii]. Power line communication technology allow data or signal transfer at a broad band speed through power lines. Power line communication is a home network technology which is used by consumer by connecting existing power lines to home appliance making smart home automation. This system reduces cost of new wiring and give consumer a flexibility to connect its appliances to internet using existing power lines to control home appliances smartly [iv].

There is a need to standardize a communication infrastructure for smart meters which can send real time data at lower costs. Therefor we reached an idea to use already built infrastructures cable (power line) efficiently for communication purpose of smart meter at low cost. Therefor we designed a low-cost smart meter and efficiently transmitted data over power line. For designing a power line modem for smart metering, reviewed the literature of current digital communication techniques, current power line modems, protocols of communications and each component which used in designing of smart meter and power line communication modems. Research consists of software and hardware design. In hardware design, modem circuit, coupler circuits, power supply, IC module and meter circuit are designed and fitted onto a display board. The software which is developed using Arduino for meters to read the current sensor (ACS712) values and convert it in digital signal for transmission and on receiving end made another an Arduino based program by which Arduino is capable to retrieve the signal coming from demodulator circuit and display it to an LCD.

The rest of the paper is planned as follows. Background of the technology needed in designing a PLC modem presented in Sec. II. System Model and mathematical justification are taken in Sec. III. Summarized results and discussions are presented in Sec. IV. Finally, we conclude the paper in Sec. V.

II. BACKGROUND

(A) Narrow Band Power Line Communication

In the field of AMI, NB PLC provided a robust alternative to wireless communications in terms of bandwidth, power, and cost requirements. The advantages and disadvantages of PLC and wireless communication are shown in Table I. NB PLC already has developed different standards for AMI, and its data rates range from 1.2Kbps to up to 128Kbps, which fulfilled the bandwidth requirements of data acquisition, lighting control, home automation and other applications. In this way, NB PLC has become very attractive technology that can serve as a smart grid communication infrastructure [v].

Table I

PLC contrasted with Wireless.

Technology	Advantaged	Disadvantages
PLC	• Available infrastructure • Large coverage • Low cost • Both power and data	• High impulsive noise • High attenuation • Electromagnetic Interference • New installation is expensive
Wireless	• Developed Technology • Fast installation • Low cost • Only for data	• Limited coverage • Limited no. of connection • Costly than existing PLC • Varying channel

In narrow band, modulation and coding of transmission frequency is in the range of 500 kHz band, therefore low fading effect observed as compare to higher frequency bands. If frequencies over 100 kHz is used, then attenuation of power line become 0.25dB/kHz. Also, if frequency increases over 10 MHz it would be much difficult to recognize the receive signal. If transmission line link longer than 400m, attenuation in signal become high at specific frequencies [vi].

(B) Modulation Scheme

In power lines, there are three primary digital modulations schemes used. All have their own advantages or disadvantages:

Amplitude Shift Keying (ASK)

Amplitude Shift Key (ASK) is a kind of modulation scheme in which digital data is represented by the variation of carrier amplitude. In ASK modulation, modulated signal amplitude is set to zero if there is low binary signal while it given carrier frequency if binary data is high. It is simplest form of digital modulation.

Frequency Shift Keying (FSK)

Frequency Shift Key (FSK) is a kind of modulation scheme in which digital data is represented by the variation of carrier signal frequency. If there is high binary signal means “1” then modulated signal will have the same frequency as of carrier signal and if there is low data signal means “0” then modulated signal will have zero frequency signal like dc zero, this type of scheme in data transmission and reception technique is called Frequency shift keying (FSK).

Phase Shift Keying (PSK)

Phase Shift Key (PSK) is a kind of modulation scheme in which sine and cosine is responsible to change the phase of carrier signal at certain interval of time. Most of the digital communication network used PSK scheme like RFID, LAN, wireless and biometric etc.

There are two types of PSK depending on the angle of phase shifting of signal.

Binary Phase Shift Keying (BPSK)

In BPSK technique sine wave reverse its, 0 and 180 degrees, it is also called phase reversal shift keying. 180-degree phase shift occurs when input signal changes its level from higher to lower binary signal.

Quadrature Phase Shift Keying (QPSK)

QPSK is a type of BPSK, it is also a Double Side Band Suppressed Carrier (DSBSC) modulation scheme, and DSBSC means that it is capable send two bits of digital data at a time. 90-degree phase shift occurs when input signal changes its level.

(C) TDA5051AT

The TDA5051AT is a complete ASK (Amplitude shift keying) modem with specific function of data transmission on power line network, it requires few external components to operate properly. It can be used for Data exchange in two wire networks by modulation technique of ASK in both AC and DC. The IC is capable to have both operation in a same package, modulation, and demodulation, so it can be used for both purpose, transmission, and reception with low baud rate data signal. To set the frequency of detection, operation and transmission, an external quartz crystal is required which will provide frequency to IC chip. Block diagram of TDA5051AT shown in Fig. 1. [vii].

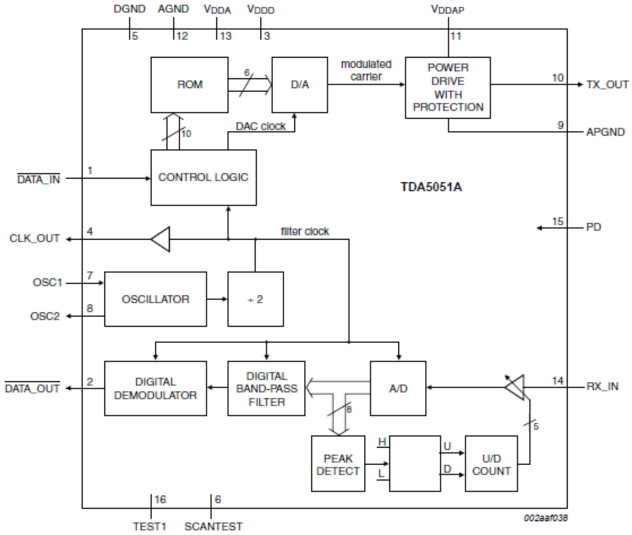


Fig. 1. Block Diagram of TDA5051AT

(D) Arduino

Arduino is open source, all in one package, comprises of both an integrated development environment or piece of software and a physical programmable circuitry (usually a microcontroller). It has micro-controller and digital input/output and analog input/output connectivity, user just need to program it for desired function. Block diagram of Arduino shown in Fig. 2. [viii].

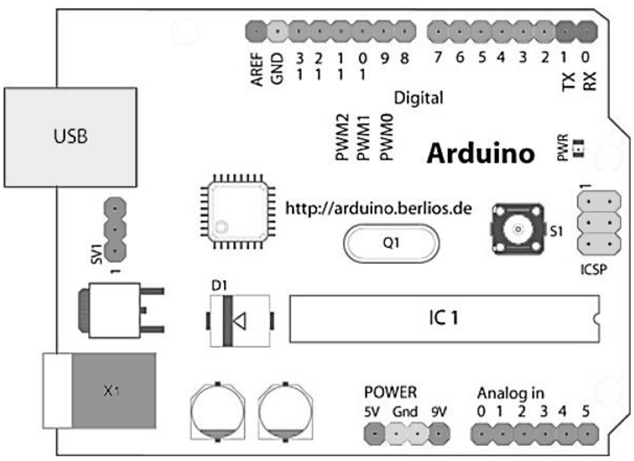
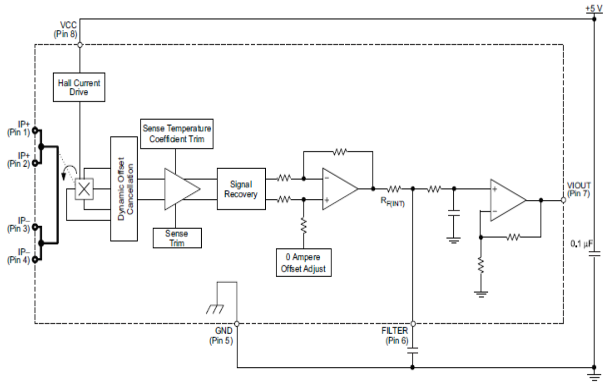


Fig. 2. Block Diagram of Arduino

(E) ACS-712

ACS-712 is linear current sensor IC based on Hall-Effect with a low resistance current conductor and 2.1 kVrms isolation. Is used to sense the current reading and converting into proportional signal at its output pin which is connected to Arduino board. Block diagram of ACS-712 shown in Fig. 3. [ix].



III. DESIGN AND METHODOLOGY OF SMART METER

The First of all smart meter read the current consumption of load then send it to modem which will modulate this low frequency signal on to high frequency 115khz signal and transmit it to coupler circuit, which is used to isolate low frequency 220v power signal with IC module. Coupler circuit superimposed high frequency data signal to AC 220v power signal. On the receiving side another coupler which is used for isolation also extract the high frequency data signal from AC 220v power signal. Demodulators demodulate the information data from high frequency signal and transmitted to display unit [vii]. Block Diagram of methodology is illustrated in Fig. 4.

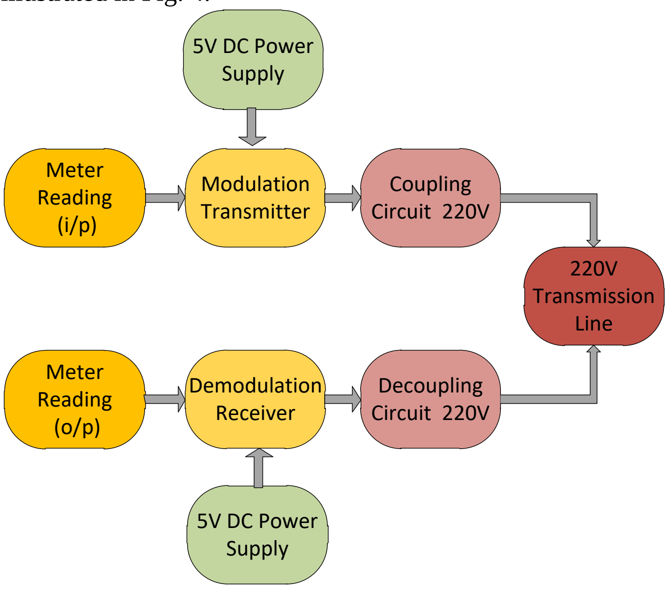


Fig. 4. Block Diagram System Model

(A) Power Line Modem Design

There are subunits required for designing of power line modem, which include digital unit, power supply and coupling circuits as shown in Fig. 5. Power supply, it is a basic requirement which is needed to operate IC modules. Digital unit is the heart of modem because it will modulate the low frequency signal to high frequency signal. Coupling circuits, it is also an important part used to isolate IC module from 220v power signal. These main subunits are as follow.

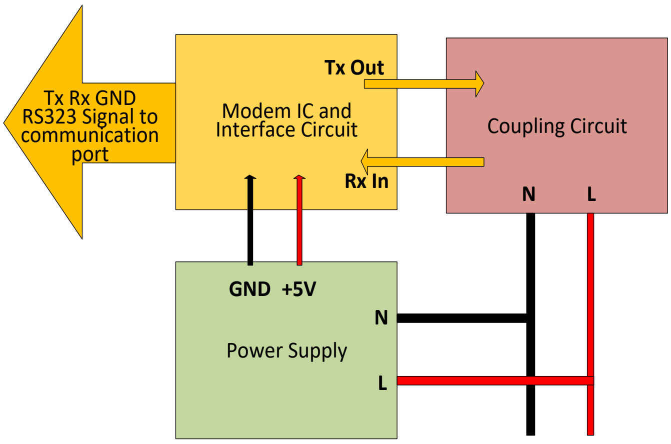


Fig. 5. Block Diagram System Model

Power Supply

A 5v dc power supply is required to drive IC chip TDA5051AT power line modem. Power supply consists of basic electronic components included few capacitors, resistors, diodes, and bridge rectifier. A step-down 220v/12v transformer is used to step down input 220v AC to 12v AC. 0.5 Amp fuse used for protection to the power supply due to sensitivity of IC chip TDA5051AT, as it is designed for only 335mA. Fig. 6 illustrated the equivalent circuit diagram of power supply for input and output current.

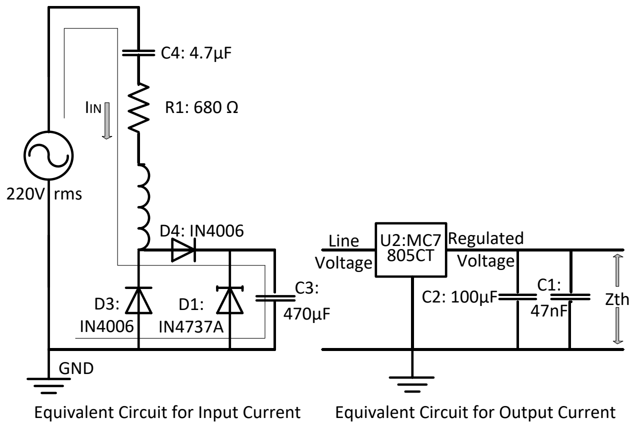


Fig. 6. Equivalent Circuit for Input and Output Current

$$V_2 = I_N(R + X_L + X_{C3+C4}) \quad (1)$$

$$230\angle 0 = I_N\left\{68 + (j\omega \times 1m) + \left(\frac{-j}{\omega \times 4.7\mu}\right) + \left(\frac{-j}{\omega \times 470\mu}\right)\right\} + 0.7$$

$$I_N = 0.335\angle 84.32\ A \quad (2)$$

$$Z_{th} = \left(\frac{X_{c1} \times X_{c2}}{X_{c1} + X_{c2}}\right) \quad (3)$$

$$Z_{th} = \left(\frac{\left(\frac{-j}{\omega \times 47n}\right)\times\left(\frac{-j}{\omega \times 100\mu}\right)}{\left(\frac{-j}{\omega \times 47n}\right)+\left(\frac{-j}{\omega \times 100\mu}\right)}\right) = 31.81\angle -90\ \Omega$$

$$I_{out} = \frac{5}{31.81\angle -90} A$$

$$I_{out} = 157\angle 90\ mA \quad (4)$$

where $\omega = 2\pi(50) = 314.159\ rad/sec$

TDA5051AT Modem Chipset Design

Design parameter of TDA5051A chipset are follows, there are number of pins which configured as per requirement. Ground connected to power down (pin 15) to disable "Power Down Mode". As microcontroller has not been used so the clock output (pin 4) left without connected to any other component. Pins 3, 11 and 13 connected to 5volts DC Supply voltage (VDDD, VDDAP, and VDDA) respectively of TDA5051AT. Ground connected to Pin 5, 9, and 12 (DGND, APGND, and AGND) respectively. As per data sheet of TDA5051A recommended to use a $2.2\ M\Omega$ resistor and a $7.3728\ MHz$ standard crystal. Both are connected in parallel with two series capacitors of $27pF$, as shown in Fig. 7.

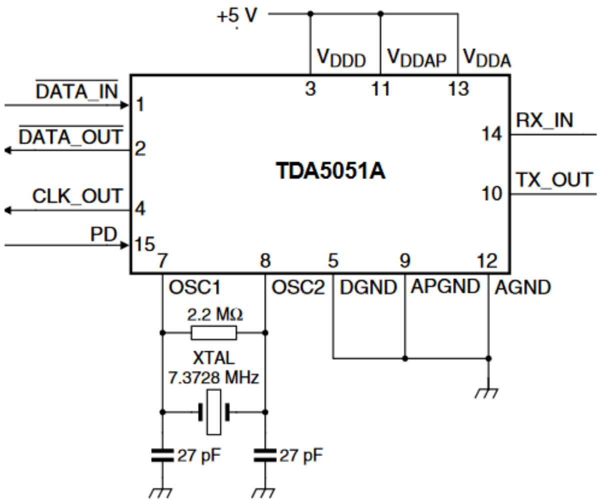


Fig. 7. Equivalent Circuit for Input and Output Current

Coupling Circuit Design

To reject 50Hz signal high pass filter is used and for anti-aliasing low pass digital filter is used as shown in Fig. 8. Two band pass LC filter is designed without any tunable or adjustable components [x]. For selecting the component, calculations were done by impedance matching.

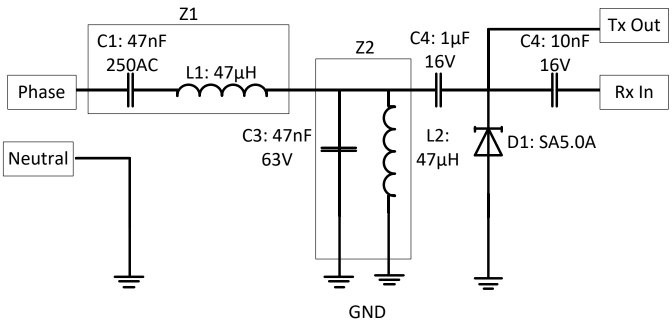


Fig. 8. Coupling Circuit with Two Bandpass Filters

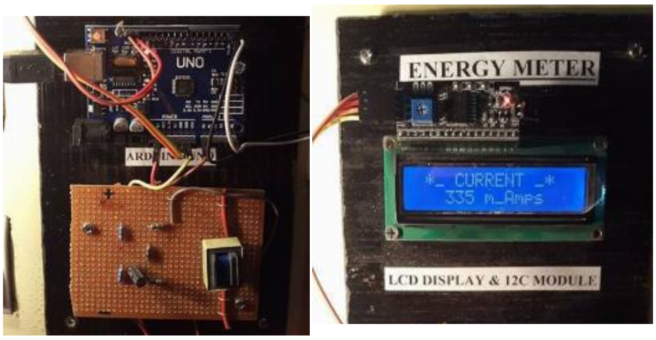
To protect IC chip from positive and negative over voltage surges a unidirectional transient suppressor (SA5.0A, D1) is connected across both TX_{OUT} and RX_{IN}. For analyzing this circuit, used basic circuit analysis technique known as superposition. Considering 230Vrms, 50Hz AC sine wave as a signal source at V_{IN}. Thevenin Equivalent at output of the; circuit can be calculated as follows.

$$Z_1 = X_{C1} + X_{L1}$$
$$Z_2 = X_{C3} \parallel X_{L2}$$
$$X_{C1} = X_{C3} = \frac{1}{\omega \times 47n} = 67725.51\Omega$$
$$X_{L1} = X_{L2} = \omega \times 47\mu = 0.014765\Omega$$
$$Z_1 = -j67725.51 + j0.014765 = -j67725.49\Omega$$
$$Z_2 = \left(\frac{(-j67725.51) \times (j0.014765)}{(-j67725.51) + (j0.014765)}\right) = j0.014765\Omega$$
$$V_{OC} = V_{IN}\left(\frac{Z_2}{Z_1 + Z_2}\right)$$
$$V_{OC} = 230\angle 90\left(\frac{0.014765\angle 90}{67725.47\angle -90}\right)$$
$$V_{OC} = 50\mu\angle 270\ V$$
$$Attenuation\,(\text{dB}) = 20\log\left(\frac{230V}{50\mu}\right) = 133.25dB$$

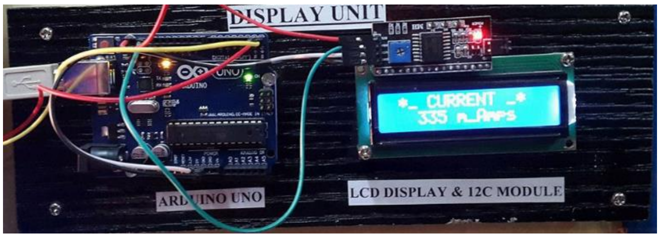
This ratio will effectively eliminate 230vrms signal from 50uV with the attenuation of 133.25dB.

(B) Digital Energy Meter Design

Designing of digital energy meter consist of Arduino UNO, current sensor ACS712 and 16 by 2 LCD display with I2C module at transmitter side. Arduino UNO and 16 by 2 LCD display with I2C module at receiver side. First programed Arduino to display the current consumption of load by transmitting the current reading which is sensed by current sensor to TX pin of Arduino. After modulation, reading sent from user (transmitter end) end to supplier (receiver end). For receiving side, receive data from demodulator and display it on LCD by used of I2C module, this unit placed on power supplier end. A signal which is sent by smart energy meter which is modulated by TDA5051AT, is received, demodulated, and displayed on display unit. Display Unit includes and Arduino UNO, LCD display and 12C Module [xi]. Complete unit of digital energy meter with transmitter and receiver is displayed in Fig. 9.



Transmitter (Consumer Side)



Receiver (Utility Side)

Fig. 9. Digital energy meter

<u>Arduino UNO code for current sensor and LCD display at transmitter end</u>

Small portion of Arduino UNO code for current sensor and LCD display at transmitter end is given below.

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <SoftwareSerial.h>
SoftwareSerial mySerial(2, 3); // RX, TX
LiquidCrystal_I2C lcd(0x3F, 2, 1, 0, 4, 5, 6, 7, 3, POSITIVE);
const int sensorIn = A0;
int mVperAmp = 185; // use 100 for 20A Module and 66 for 30A M
double Voltage = 0;
double VRMS = 0;
int AmpsRMS = 0;
void setup() {
  Wire.begin();
```

<u>Arduino UNO code for LCD display at receiver end</u>

Small portion of Arduino UNO code for LCD display at receiver end is given below.

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <SoftwareSerial.h>
SoftwareSerial mySerial(2, 3); // RX, TX
LiquidCrystal_I2C lcd(0x3F, 2, 1, 0, 4, 5, 6, 7, 3, POSITIVE);
void setup()
{
 Wire.begin();
 Serial.begin(9600);
 lcd.begin(16, 2);          // columns, rows.  use 16,2 for a 16x2 LCD, etc.
 lcd.clear();
 Serial.println("Recieving side ");
```

IV. RESULTS AND DISCUSSION

In Following simulation and hardware test, listed in Table II has been done for implementation of smart meter and data transmission over power line.

Table I
Simulation and Hardware Test of subunits

S.No.	Test	Simulation	Hardware
1	+5V Power Supply Test	√	√
2	Coupling Circuit Test	√	√
3	Coupler to Coupler Test (Without 220V AC)	√	√
4	TDA5051AT Modem IC Test		√
5	Test 01 5v to data input pin		√
6	Test 02 Ground to data input pin		√
7	Test 03 300Hz Signal to data in		√
8	TDA5051AT Modem to Modem Communication Test		√
9	TDA5051AT Modem IC & Coupler Test		√
10	Modem to Modem 220V AC test		√
11	Power line Data Communication		√
	Complete System Test		

In complete system test, first connect the load to the system which consume current. Measured load consumption through current sensor. The Arduino of the smart meter, which is designed in this research, convert this analogue consumption values into digital signal and display this on the LCD. This digital signal is sent by TX pin of Arduino to TDA5051AT (Modem IC) data input pin. Modem modulate this low frequency signal into high frequency signal and sent this high frequency (115khz) to receive input pin of coupler circuit. Coupler circuit isolate 220v power signal and modem and let the higher frequency signal to pass from one end of main power line to another receiving end. This high frequency signal pass through up to 50 m. Another coupler circuit at receiver end, which is the same as first coupler circuit perform isolation and let the high frequency signal pass to the received input pin of receiver modem where modem demodulate it and sent its low frequency signal to Rx pin of display unit. Arduino UNO processed and displayed the same reading which were transmitted from smart meter. Complete system shown in Fig. 10.

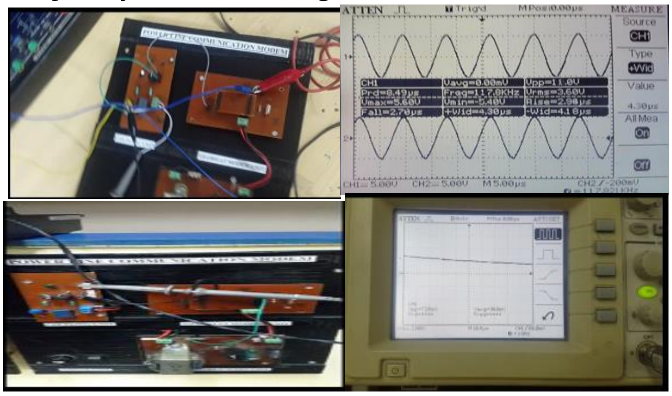


Fig. 10. Complete system

V. CONCLUSION

The purpose of implementing, smart meter, its coupler, its power supply, writing program for Arduino and designing other unit, to fulfill the data requirement of next generation network whether its power system or communication system. Power line communication technology by which the information can be transmitted and received is very low cost because power line infrastructure is already exits. This research opens the door into information and communication technology at low-cost existing infrastructure. Successfully implementation power line modem, smart meter and over all power line communication also their successful test showed that the PLC technology is possible not only on paper but also in practical. For future direction OFDM can replace the ASK for better spectral efficiency.

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