Design and Implementation of a Smart Meter for Load Management

Abdul-Razzak Shehab Hadi¹, Mohammed Chessab Mahdi², Abed Al-Abass Muhseen Jassem³, Ali Sahib⁴

¹Department of Electrical Engineering, University of Kufa, Najaf, Iraq
²Department of Information Technology, Al-Furat Al-Awsat Technical University, Najaf-Iraq.
³Department of Mechanical Techniques, Kufa Technical Institute, Al-Furat Al-Awsat Technical University, Najaf, Iraq
⁴Department of Electrical Engineering, University of Kufa, Najaf, Iraq

Abstract In this work, a method is outlined to convert a conventional electro-mechanical meter into a digital power meter as part of an Automated Meter Reading (AMR) system using a simple and cost-effective technique. A conventional electro-mechanical meter was converted to emit digitised pulses with the addition of an optical encoder, allowing automatic transmission of meter reading data and detection of meter tampering. In testing the proposed AMR system, the meter readings as read from the LCD were found to offer an accurate representation of the total power consumed. Further improvements suggested to enhance the functions of the AMR system, including load management and pre-payment. The proposed meter offers substantial savings for electric utility companies as well as enabling users to take advantage of fully automated meter readings.

1. Introduction

Conventional meters are electro-mechanical devices that measure the consumption of power and require regular readings to be taken in situ [1], while smart meters are measurement devices with electronic components that broadcast information about billing using electronic systems. In recent years, smart meters have gradually begun to replace traditional meters [2], as smart meter designs often meet the requirements of the service provider as well as the beneficiary customer more effectively [3]. The main features that smart meters provide to consumers are real-time statistics and pricing, and the technology can be utilised for both industrial and commercial customers who require more accurate and timely billing data.

Smart meters also provide utility companies with the ability to manage the power grid more effectively by monitoring and utilising information about energy consumption and quality, which can be done continuously, reliably, and remotely using smart meters. A smart meter system includes three subsystems: the meter, the communication subsystem, and control devices [4]. Smart meters utilise different wireless communication technologies such as Bluetooth, GSM, wireless systems, GPRS, ZigBee, and Intelligent SMS [5], and smart metering systems with communication links and regulation devices solve multiple problems inherent in conventional metering systems.
Smart meters can offer multiple features such as telecommunication connection and disconnection, tamper protection, fault detection, billing information, pricing, and remote tariff setting. Further, as the smart meter system offers benefits such as controlling and monitoring energy systems effectively, operational decisions can be made in a more timely manner to minimise outages and losses. Smart meters can also improve the operation of Supervisory Control and Data Acquisition (SCADA) systems.

The combination of electronic meters with one-path communications technology to gather meter data generates Automated Meter Reading (AMR) systems, while the combination of electronic meters with two-path communications technology for information, monitoring, and control creates Advanced Metering Infrastructure (AMI) [6], with the latter developing out of the former over time.

In this work, a method is outlined to convert a traditional electromechanical meter into a digital energy meter system using simple, low-cost techniques. The resulting digital energy meter can then be used as part of an AMR system to allow automatic transmission of meter readings, data reading, and detection of tampering with the meter.

This paper thus presents a smart meter implementation with overload management in detail. Section II describes the main components required to implement the smart meter and their specifications, while the results of the experiment are discussed in section III, and section offers a conclusion.

2. Research Method

The conventional type of electricity meter is an electromechanical watt-hour device. On a single-phase AC supply, an electromechanical induction meter works by counting the revolutions of a non-magnetic yet electrically conductive metal disc that thus revolves at a speed directly related to the power passing through the meter, making the number of rotations proportional to the energy usage. The voltage coil uses a small and relatively constant amount of power, typically around 2 watts, which is not counted within the usage measured by the meter.

Smart meters are beginning to be utilised more widely, however, as they can improve balancing across the electrical grid and the efficiency of electrical power distribution by providing extra information. These electronic meters show the energy consumed or used on an LCD or LED display, and some also transmit readings to remote locations. In addition to measuring the energy used, these electronic measuring devices can also record other load and supply parameters such as the rate of immediate use and the maximum rate of use, power factors, voltages, and interactive energy used. There are distinct technological differences between smart meters and older electromechanical metering devices, yet the electric industry must exercise caution to ensure that the same precision is applied to assessing the accuracy of smart meters as in older electromechanical metering devices, particularly for revenue billing applications. Nevertheless, once such checks are made, smart meters offer more security and more accuracy with lower power consumption, lower cost, smaller size and the ability to make modifications and add options more easily than with a conventional electromechanical meter.

2.1. Smart Metering System Components

The major components inside the proposed smart meter are listed below.

2.1.1 Micro Controller (Arduino Nano)

The Arduino Nano is an integral micro controller board based on the ATMEG 328p. It has 22 input/output pins in total, of which eight are analogue and 14 are digital. It has a 16MHz crystal oscillator [7] and it can use supply voltages from 5V to 12V. The Arduino Nano supports several different methods of communication: SPI Protocol, I2C Protocol, and Serial Protocol. The Arduino Nano also has a USB Pin, which is used to upload code, as shown in Figure 1.
2.1.2 LCD I2C- (Liquid Crystal Display) (4*20)

Liquid crystal displays are used in a wide range of applications. The 4 x 20 LCD, which can display 4 lines with 20 characters per each line, as shown in Figure 2, is a very basic module, generally used in circuits and programmable devices in preference to the seven segment or other multi segment displays used in older projects [8]. LCDs are easily programmable, economical, and have no limitations with regard to displaying special characters.

2.1.3 GSM SIM 900

A GSM/GPRS-compatible Quad-band cell phone sim operating on a frequency of 850/900/1800/1900MHz, which can be used not only to access the Internet, but also for general communication and sending SMS messages was adopted [9]. Externally, it has L-shaped contacts on all four sides, allowing it to be soldered both on the sides and at the bottom. Internally, the module is managed by an AMR926EJ-S processor, which controls the phone communication. The receiving circuit is shown in Figure 3.

2.1.4 Current Transformer Sensor (CT Sensor)

Current sensors have a secondary function as current transformers, while the conductor carrying the current to be measured functions as the primary transformer. Measurement reliability can be improved by increasing the number of primary turns on the conductor. Applications of this include identification of branch circuit overload and load drop or shutdown as required to protect the system.
Current Sensor Specifications
The onboard precision micro current transformer and sampling resistor module utilises 5 AMP alternating current; the corresponding analogue output is 5A/5 mAMP. The PCB board size is 18.3 mm x 17mm, which is 5_Rated for primary current at 50/60 Hz and 5 AMP. Maximum primary current is at 50/60 HZ and 20 AMP. The 7_Turns ratio NP: NS is 1 : 2.500, and winding resistance at 20 °C = 155 Ω. The operating temperature range is -40 to 85 °C.

2.1.5 Voltage adapter:
An AC voltage measurement is required to calculate apparent power and real power. This measurement can be made safely, without high voltage work, by using an AC to AC (220 V/6-0-6 V) power adaptor. The transformer in the adapter prolongs isolation from the high voltage main and converts the alternating high voltages into alternating low voltages. Figure 5 shows the voltage adapter.

2.1.6 Infrared sensor (IR sensor)
The sensor module light is adjustable to suit its surroundings and has a pair of infrared transmitting and receiving tubes [10] that send a certain frequency when detection in a given direction meets with barriers (reflecting surface). The reflected infrared signal is subject to comparator circuit processing, and a green indicator will light up when the signal output link to output digital signal (a low-level signal) can be accessed. A variable resistor knob is used to calibrate the detection distance, with an effective distance range of 2 to 30 cm, and a working voltage of 3.3V to 5V. Such sensors are frequently used in robot obstacle avoidance or obstacle avoidance in cars. Figure 6 shows the IR-sensor.
2.2 System Architecture

Figure 7 shows the system architecture of proposed meter. As shown, the sources represent the feed from the utility company, and in the prototype, the load is assumed to have a unity power factor that is symmetric and balanced. These feeds are connected to loads across the microcontroller, which sends signals to the relay, which in turn supplies the load with power through relays, which are normally in open contact positions. The measurements of current, power, and power per hour are calculated by the microcontroller software. Current transformer sensor measurements are used to execute appropriate software on the microcontroller for that purpose, and a telecommunication signal informs users about the current situation.

2.3 Software

A smart meter must execute two tasks: measuring consumed electrical power and performing load management.

A. The following steps explain how the proposed meter measures consumed electrical power:
   1- Currents are read from current sensors (CT1, CT2, and CT3)
   2- Total current \( I_T = I_1 + I_2 + I_3 \) is calculated
   3- Total voltage is read from the voltage transformer,
4- Total power (Total Power = Total Current × Total Voltage × cos wt) is calculated, under the assumption that the power factor is unity.

5- The power (PT, P1, P2, P3) and current (IT, I1, I2, I3) are displayed on the LCD (Liquid Crystal Display).

B. Load Management:

Here, the digital power meter divides the load into three types according to priority: The first load, which has the highest priority and represents the main functions; the second load, which is less importance than first load but more importance than third load; and the third load, which has lowest priority because it is less important than the other loads.

The following steps explain how the proposed meter manages the load:

1- When the total current of the load is less than 3 Amp, all loads are in working condition.

2- If the total current increases to 3A, the microcontroller can sense this using the current sensors; it then sends two signals. The first signal is sent to the relay to open the lower priority load (third load in the case study) and the second signal is sent to GSM to alert the user to the increase and the fact that the load is separated from the electrical system.

3- If the load increase continues, the second load is separated at a specified value.

A flow chart of the proposed meter software is shown in Figure 8.

![Figure 8. Software flow chart](image-url)
3. Results and Discussion

A system prototype and control panel were built as shown in Figures 9 and 10. The values of the load currents were controlled by changing the values on the variable resistors, which were connected in series with each load. Software was written to execute the two main tasks of the system, measuring the consumed electrical power and load management. To test the proposed system with regard to the first task, the meter readings as read from the LCD were compared to total power consumed. For the second task, when the total current of the loads was less than the maximum allowed value, all loads were observed to be in working condition. The variable resistors in the control panel were then set so that the total current exceeded the maximum allowed value, and the third load (lowest priority) was separated; the user received a message showing the amount of increase and the load being separated from the electrical system, as required. When the variable resistors in the control panel were set so that the value of the total current is greater than the maximum allowed value, however, although the third load was already disconnected, the second load was also separated and the user received a further message showing the amount of increase and the further load being separated from the electrical system. As an additional check, a motion sensor was added to the system; when no one is near to the location to check the meter, this sensor sends a signal to the micro controller, which turns off the system.

4. Conclusion

This paper describes the various components used to build an Automated Meter Reading system supported by the required software. The results indicate that the proposed system could lead to substantial savings for utility companies as well as enabling users to benefit from fully automated meter readings. The system can control the amount of energy consumed by managing loads according to the priorities set by the user, thus avoiding waste in energy consumption. The proposed system also notifies the user about the amount of capacity consumed and any separated loads. Additional improvements could also be made to enhance the functionality of the proposed system to include load automation and pre-payment.
References

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Meter code

```c
#include <LiquidCrystal.h>

int currentPin = 1; //Assign CT input
double kilos = 0;
int peakPower = 0;
LiquidCrystal lcd(8, 9, 4, 5, 6, 7); //Assign LCD screen pins

void setup()
{
    lcd.begin(16,2); // columns, rows. use 16,2 for a 16x2 LCD, etc.
    lcd.clear();
}
```
lcd.setCursor(0,0);  // set cursor to column 0, row 0 (the first row)
lcd.print("Running");
}

void loop()
{
    int current = 0;
    int maxCurrent = 0;
    int minCurrent = 1000;
    for (int i=0 ; i<=200 ; i++)  //Monitors and logs the current input for 200 cycles to determine max and min current
    {
        current = analogRead(currentPin);    //Reads current input
        if(current >= maxCurrent)
            maxCurrent = current;
        else if(current <= minCurrent)
            minCurrent = current;
    }
    if (maxCurrent <= 517)
    {
        maxCurrent = 516;
    }
    double RMSCurrent = ((maxCurrent - 516)*0.707)/11.8337;    //Calculates RMS current based on maximum value
    int RMSPower = 220*RMSCurrent;    //Calculates RMS Power Assuming Voltage 220VAC, change to 110VAC accordingly
    if (RMSPower > peakPower)
    {
        peakPower = RMSPower;
    }
    kilos = kilos + (RMSPower * (2.05/60/60/1000));    //Calculate kilowatt hours used
delay (2000);
lcd.clear();
lcd.setCursor(0,0);           // Displays all current data
lcd.print(RMSCurrent);
lcd.print("A");
lcd.setCursor(10,0);
lcd.print(RMSPower);
lcd.print("W");
lcd.setCursor(0,1);
lcd.print(kilos);
lcd.print("kWh");
lcd.setCursor(10,1);
lcd.print(peakPower);
lcd.print("W");
}