Automatic Electric Billing System using Digital Wattmeter and Powerline Carrier System

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Abstract

The "Information Age" in electricity metering has arrived. Today's power measurement applications demand that energy meters be both intelligent and powerful to satisfy the challenges of a competitive marketplace. DIGITAL WATTMETER with a suitable LED display is such a potent device to accurately measure energy consumption and demand in the real world so to reduce system losses and consumer dissatisfaction.

This paper describes an alternative infrastructure design of the electric meter reading system to eliminate the manual meter reading by remote monitoring of the power consumption and meter status using powerline carrier system and digital wattmeter. At a certain predefined time interval, the central system connected to each meter through powerline networking would collect the readings and automatically print the billing at the end of the month.

Keywords

Digital Wattmeter, AMR, PLM, PLN, HCS, DCU

INTRODUCTION

Wattmeter is an abundant and necessary tool for electric utility companies. Electric power is measured by means of a wattmeter. The most common of these devices are analog in nature and are not easily read by the average electric energy consumer. In order to know the cost of the electric energy that has been used in a set amount of time, one must take a meter reading, wait for the desired amount of time, take another meter reading, calculate the difference between the two readings, and calculate the cost by using the cost per kilowatt hour found on one's electric utility bill. This is how electric utility companies compute a consumer's bill, and they dedicate an enormous amount of time to this endeavor. The idea is to automate this process and make it available to the average electric energy consumer so that it would be beneficial for both electric utility companies and their respective consumers in the long run.

Electric energy is so widely used that many consumers take it for granted. Rising fuel cost and personal economic troubles can suddenly bring such a common thing into focus. It would be useful to know at any time during the month whether one was using more electric energy that one could afford.

The first step to automate this process is to use a digital wattmeter which would show digital LED display on the consumer side so that the consumers can easily get the readings and simply multiply it with the cost per kilowatt hour to know their consumption of the electric energy. The second step is to derive a way that would eliminate the meter reading process by the company service man every month so to calculate and prepare the billing. Now this could be done using the power line carrier systems to send data from each meter to a central server at a certain interval.

THEORETICAL BACKGROUND OF THE STUDY

For customer usage data to be of any value, it first must be obtained, and to realize the data's true functionality, it must be obtained in a timely, consistent manner. Automatic Meter Reading has made that timely and accurate acquisition of data possible. Prior to Automatic Meter Reading System's emergence, operational utilization of customer usage data was either impossible or unfeasible.

Automatic meter reading was first tested 30 years ago when trials were conducted by AT&T in cooperation with a group of utility companies and Westinghouse. After those successful experiments, AT&T offered to provide phone system-based Automatic Meter Reading services at $2 per meter. The price was four times more than the monthly cost of a person to read the meter-50 cents. Thus the program was considered economically unfeasible.

The modern era of automatic meter reading began in 1985, when several major full-scale projects were implemented. Hackensack Water Co. and Equitable Gas Co. were the first to commit to full-scale implementation of automatic meter reading on water and gas meters, respectively. In 1986, Minnegasco initiated a 450,000-point radio-based automatic meter reading system. In 1987, Philadelphia Electric Co., faced with a large number of inaccessible meters, installed thousands of distribution line carrier automatic meter reading units to solve this problem. Thus, automatic meter reading is becoming more viable each day. Advances in solid-state electronics, microprocessor components and low-cost surface-mount technology assembly techniques have been the catalyst to produce reliable cost-effective products capable of providing the economics and human benefits that justify automatic meter reading systems on a large, if not full-scale basis. Almost all the meter reading systems consists of three primary components.

1. ***Meter interface module*** with power supply, meter sensors, controlling electronics and a communication interface that allows data to be transmitted from this remote device to a central location. In many instances, this communication interface is bi-directional and allows central office signals to be received by the remote unit as well. Every electric, gas or water meter must have such an interface unit to be remotely read. Some key components of the

remote device may be shared by more than one meter without regard for the type of meter; i.e., electric, gas or water.

2. ***Communications systems*** used for the transmission of data and control send signals between the meter interface units and the central office. Typically, such communications take the form of telephone, powerline carrier (PLC), radio frequency (RF), or cable television. The system components in the communications system depend on the communication media used.

3. ***Central office systems equipment*** including modems, receivers, data concentrators, controllers, host upload links, and host computer. Many utilities have for some time been taking advantage of electronic meter reading systems using hand-held data terminals that communicate with a central controller via phone lines. There is great similarity between the host side electronic meter reading and automatic meter reading system function.

There are three major building block functions that the meters interface and related electronics must perform. These are common to electric, gas and water implementations. First, an electromechanical or electro-optical interface must be incorporated into or attached to the meter. This converts information conveyed by the meter's mechanical register indexes, or dial readings, into electronic signals which may be processed, manipulated, stored and transmitted.

The second functional building block is a controller unit consisting of a low-voltage power supply, signal processing electronics, microcomputer, random access memory and program memory used to store the real-time run or operating system program. The controller unit is used to process the signals originating from the meter's electromechanical or electro-optical interface device. In effect, the controller unit converts the meter's electromechanical interface device signals into computer type electronic digital representations of the meter's exact index or dial readings-much as a calculator converts keypad entries into numbers appearing on the display. The controller's RAM memory maintains an up-to-the-minute mirror image of the meter's dials and as the dials increment, so do the numerical representations stored in RAM.

The third functional building block is the communication scheme and its associated transmit/receive electronics. Generally, meter-to-utility host communications use one or more transmission techniques: telephone, powerline carrier, radio frequency through the airwaves, or television cable. There are many sub-categories of each of these communication forms having to do with data flow, modulation techniques, distance from remote site to central station and data transmission rates.

The automatic meter reading system starts at the meter. Some means of translating readings from rotating meter dials, or cyclometer style meter dials, into digital form is necessary in order to send digital metering data from the customer site to a central point. In most cases, the meter that is used in an automatic meter reading system is the same ordinary meter used for manual reading. The internal mechanism used for metering consumption is identical in both cases. The one difference is the addition of some device to generate pulses relating to the amount of consumption monitored, or generate an electronic, digital code that translates to the actual reading on the meter dials.

The full-scale implementation of automatic meter reading requires that a data communication network be established that effectively links every utility customer with the utility's central office. The actual amount of automatic meter reading-related data and its frequency of transmission is very low. These factors contribute to the difficulties encountered in the economic justification of automatic meter reading systems. There are, however, a myriad of services and functions that can be accomplished through this communication system, some of which significantly reduce a utility's operating costs and some of which can actually generate additional revenues. The incremental costs associated with incorporating these functions in the automatic meter reading system controllers is marginal. Payback can vary enormously. In theory, it is almost possible to finance a full-scale automatic meter reading system installation through the resulting costs savings and new revenue-producing services.

POWER LINE AS A TRANSMISSION MEDIUM

Power line communications stands for the use of power supply grid for communication purpose. Power line network has very extensive infrastructure in nearly each building. Because of that fact the use of this network for transmission of data in addition to power supply has gained a lot of attention. Since power line was devised for transmission of power at 50-60 Hz and at most 400 Hz, the use of this medium for data transmission, at high frequencies, presents some technically challenging problems. Besides large attenuation, power line is one of the most electrically contaminated environments, which makes communication extremely difficult. Further more the restrictions imposed on the use of various frequency bands in the power line spectrum limit the achievable data rates.

Power lines connect the power generation station to a variety of customers dispersed over a wide region. Power transmission is done using varying voltage levels and power line cables. Power line cable characteristics and the number of crossovers play an important role in determining the kind of communication technology that needs to be used.

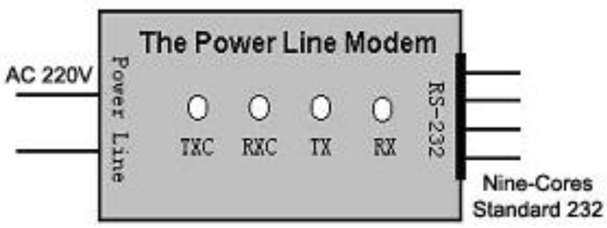
The first power line carrier services concentrated on transmission and reception in the low frequency band. In Europe, the European Committee for Electrotechnical Standardization, CENELEC, produced EN50065, a standard covering the communications requirements for transmitting and receiving signals over the low voltage distribution network, both to the building and in building communication, in the frequency range 3 kHz to 148.5 kHz. The USA frequency band covers the frequency range 45 kHz to 450 kHz.

The services provided in this frequency range included remote meter reading of all types of utility meter, basic load and energy management. This type of service required only low data rates, which could be provided efficiently at these low frequencies. As the demand for more services into buildings grows, however, competition between the major cable companies intensifies. Because of the shortage of bandwidth, companies are exploiting other parts of the frequency spectrum in the range 1MHz to 30MHz. This allows them to enter into broadband services associated with high speed data services, such as the Internet.

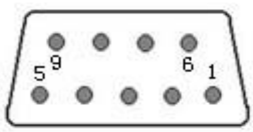
POWER LINE CARRIER MODEM

The power line modem (PLM) is a dedicated device for transferring data over low voltage power line. Using the extensive power line cable network in a region that is distributed by a single transformer, one can use a multiple PLM to form a data network among the various data terminals. Thus, a data communication network infrastructure can be formed among all the data terminals. The unit can be used in centralized electric meter reading, remote monitoring of electrical equipment, building automation and security control, stage lighting and street lighting control applications, information displays and it can also play a role in the final leg of Internet connection in special circumstances.
The power line modem uses the power line cable as communication medium. It is convenient as it eliminates the need to lay additional cables. The modem at the transmission end modulates the signal from data terminal through RS-232 interface onto the carrier signal in the power line. At the receiving end, the modem recovers the data from the power line carrier signal by demodulation and sends the data to data terminals through RS-232 interface.

Structural Diagram



RS-232 Connection Pin Definition



Pin 2: Data Input
Pin 3: Data Output
Pin 4: DTR (out)
Pin 5: Ground
Pin 7: RTS (in)

LED Display Descriptions

TX: Lights on when PLM sends data to PC via RS-232
RX: Lights on when PLM receives data from PC via RS-232
TXC: Lights on when PLM sends carrier signal onto power line
RXC: Lights on when PLM receives carrier signal from power line

Main Features

- PLM can be used for broadcasting in a one-to-many manner without the need to worry about handshaking[1]
- PLM can be either master or slave, depending on the pin definition of RS-232. There is no prior classification of master-slave role for the modem.
- A PLM acting as master can be designed to work in a 3-phase manner

Operating Environment

Power: 220 V +/- 20%, 50 Hz +/- 5%
Temperature: -10 ºC ~ +50 ºC
Relative humidity: ≤ 95%, non-condensation

DIGITAL WATTMETER FOR COMPETITIVE MARKETPLACE

Digital wattmeter is an electronic device to measure electric power. The difference between an analog and a digital wattmeter is that in an analog wattmeter the display is synchronized in an analog format and most consumers cannot read/understand the display.
It requires a special type of gadget to read the value of such. The accuracy of the reading is also questionable sometimes and the consumers are not mentally satisfied if their bills are high since they cannot monitor by their own. There’s no transparency or harmonious relationship between consumers and the service providers.
The proposed system intends to design and implement a digital wattmeter for measuring power in a mains-driven load, using digital signal processing[2] (DSP) technology. The measurement would be based on instantaneous sampling of the voltage and current waveforms, which would be multiplied by the digital signal processing chip, and a suitable LED display would be provided which is easily readable by consumers. So the precision and the accuracy of the readouts are highly reliable. The instrument would also measure true RMS current and voltage, and possibly power factor and distortion factor. Nonsinusoidal waveforms should be catered for. To accomplish this, the measuring circuit would use an ultra fast Digital Signal Processor (DSP) and 12bit A/D Converter to sample the current and voltage inputs and calculate RMS energy. Each measured quantity is evaluated on per cycle basis with over 10 million calculations performed each second. The resulting real, reactive and apparent energy quantities represent the "true" energy within the input signal, and not just an average or peak level. Ultra fast sampling provides enhanced resolution of the waveform for better accuracy.
A circuit miniature of the powerline modem would be embedded in the digital wattmeter which would be used to communicate with the central server through powerline carrier system.

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[1] Handshaking is the way in which the data flow across the interface is regulated and controlled.

[2] Digital Signal Processor is a microprocessor-like device designed to process analog to digital (& vice-versa) data streams. DSPs are used for a variety of devices in personal computers, including high-speed modems, multimedia sound boards, and real-time audio/video compression and decompression hardware.

THE INFRASTRUCTURE DESIGN OF THE PROPOSED SYSTEM

It is stated earlier that most of the automatic meter reading systems still uses the analog wattmeter. An intelligent meter interface unit (MIU) is connected to the analog meter that collect, process, and record power consumption data. It picks up the pulse output of the meter and converts the measurement of the meter into a digital format suitable for data processing. Data stored in the MIU are transmitted to the DCU via telephone line, or powerline carrier system through the built-in Modems. There are two types of MIUs, a single-channel type connected to a single meter only, and a multi-channel type, which can be connected up to 16 meters. In projects where meters are scattered around in an open area, single-channel MIUs are usually used for individual meters. But for projects where meters are grouped together in a meter room or cabinet, Multi-channel Meter Interface Units (MMIU) is more cost effective.

Still the problem is there. The utility provider companies are mostly benefited, since it would eliminate the meter reading process. But the consumers are not that benefited in the sense that they cannot monitor their consumption just by sitting at home because of the analog readout of the meter. They need to wait for the billing. The proposed system aims to eliminate this dilemma. As it was mentioned earlier that the proposed system would use a special type of digital wattmeter with a suitable display provided for the consumers almost all the consumers would appreciate it.

System Overview

The proposed remote Automatic Meter Reading System is a host driven, multi-level network system consisting of a Host Central Station (HCS), Data Concentrator Units (DCU) and Digital Wattmeter (DWM) with built-in Power Line Modem.

The DCU and all the DWMs connected to it can be considered as a sub-system of the HCS. The sub-system is set up with a DCU monitoring the low voltage power zone downstream of a Distribution Transformer. The DCU can be viewed as the front end of the sub-system, collecting meter readings from all the DWMs connected to it through the low voltage power line carrier (PLC) and communicating with the HCS through the communication channel.

There are basically two stages of communication in the system, namely, that between the DWMs and the DCU, and that between the DCUs and the HCS. The communication channel or medium used between DWM and DCU is the Power Line; and the channel used between DCU and HCS can be with a standard RS-232[3] interface or through a modem.

A system block diagram of the proposed system is shown in Figure 1 so that it would be easier to understand.

[3] RS-232 Interface: Interface between Data Terminal Equipment and Data Communications Equipment employing serial binary data interchange.

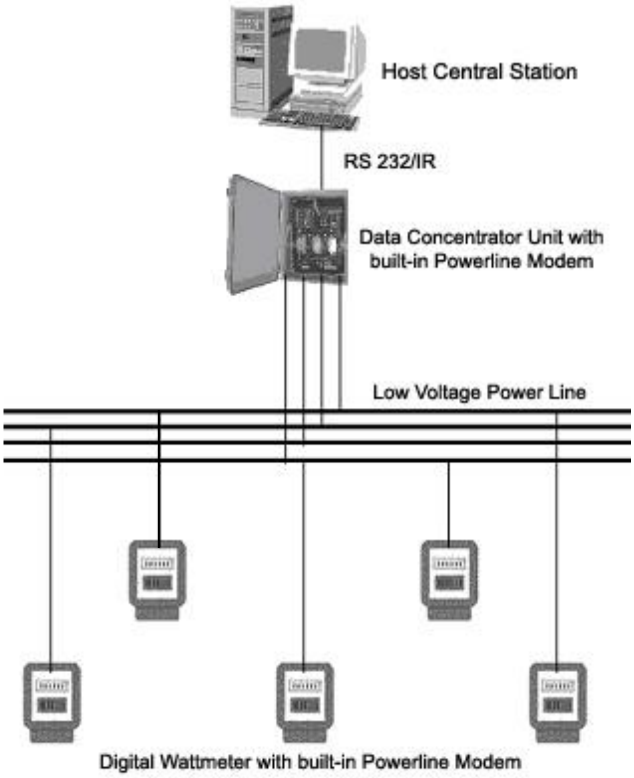

Figure 1. System block diagram of the proposed system.

Operating Principle

The communication device for the PLC communication system is a built-in Power Line Modem (PLM), which transmits and receives data over the power line. Both the DWM and the DCU contain the PLM device. The binary data stream is keyed onto a carrier signal by means of the Frequency Shift Keying (FSK)[4] technique. The central frequency is shifted +0.3 KHz to represent 1 or 0 of the binary data stream. This signal is then coupled onto the power line by the PLM. At the receiving end, an identical PLM will detect the signal and convert it back to a binary data stream. The PLMs operate in a Half Duplex, two-way, Time Division Multiplex[5] communication mode. Two-way communication between DCU and DWM is essential in establishing a proper communication channel, for system synchronization and status reporting. In Automatic Meter Reading Systems, transmission speed is not a great concern but reliability is important. The data rate of the PLC channel can be set at 600 bps, to ensure communication over a longer distance and reduced transmission error. With the sensitive signal detection and sophisticated digital filtering technique, this PLC communication could be highly immune to electrical noise and interference.

[4] Frequency Shift Keying is a digital-to-analog modulation technique. Data is transmitted by shifting between two close frequencies with ones represented by one frequency and zeros by the other.

[5] Time-division multiplexing (TDM) is a method of putting multiple data streams in a single signal by separating the signal into many segments, each having a very short duration. Each individual data stream is reassembled at the receiving end based on the timing.

Data from all the Digital Wattmeter (DWM) are transmitted to the DCU via the power line through the built-in Power Line Modems (PLM). Communication is initiated by the DCU, which polls the DWM by calling its address. Data received from different DWMs are stored in the corresponding Load Data Records in the Flash memory of the DCU. The DCU supports communication with any upward equipment in conformity with RS-232 standard.

The Host Central Station (HCS) is the control center of the system, where all the functions of the system are controlled and monitored. The HCS passes instructions and information requests onto the Data Concentrator Units (DCU) by calling their addresses, and the DCU will respond accordingly. The address codes of the DCUs are stored in the HCS. With sufficient mass storage, theoretically all DCUs can be covered by the HCS. In actual fact the maximum number of DCUs can be connected to a HCS is about 1000 as it will be limited by the required response time and efficiency of data management. In case of failures in self-diagnostics or any abnormal behavior of the DWMs, the DCU can also make requests to report to the HCS. The HCS will convert the data received into a text file compatible with the corporation's existing Meter Reading Management System, and store it in the Hard Disk Drive. File transfer between the HCS and the Corporation's MIS system can be done through standard input/output ports, such as RS-232. The host station would have the ability to automatically calculate the power usage between two times of consecutive readings and automatically print the billing at the end of a certain interval. What the electric utility companies would do is just to send the billing at the address specified in the printed bill.

CONCLUSION

The electric meter serves as the primary touch-point between the electric utility and the electric utility customer. Whether that customer is commercial, industrial or residential, the usage monitored by electric meters has tremendous value to the utility. Automatic meter reading technology has promised to make the retrieval and analysis of that customer usage data easier, less expensive and more accurate, but the electric utility industry, by and large, has been slow to adopt Automatic Meter Reading System. Cost justification is likely the main reason for the trepidation utilities experience when thoughts turn to large-scale Automatic Meter Reading implementations-and with good reason. Automatic Meter Reading implementations require a sizable upfront investment.

But a growing number of forward-thinking utilities have found Automatic Meter Reading System's upfront cost to be a small price to pay for the potential value the technology can provide in terms of accurate billing, improved customer service and operational efficiency.

The projected benefits of the proposed system follow:

- Improved cash flow through more accurate data.
- Obtain more easily (and in some cases, instantly) initial and final readings for opening and closing accounts.
- Accurate bills would reduce customer queries and complaints.
- It would reduce revenue loss through fraud from tamper or theft due to more accurate monitoring of consumption.
- It would reduce meter reading costs as the regular meter reading can be done remotely instead of using meter readers.
- Improved load management and harmonizing supply and demand.
- Immediate access to extensive metering data and information including volume and quality of supply, meters own state and tampering reports.
- Reports and analyses of meter status, energy usage and energy quality can be produced for individual meters or groups of meters in a short period of time.
- Billing can be sped up because end of month readings can be correlated in the first few hours of the new month.
- It would enable custom billing dates.
- Improved revenue forecasting, by tying detailed consumption information to production data and expected billings.
- Increased revenues from reducing system losses or replacing older inaccurate meters.

Intangible Benefits, even though they cannot be easily quantified, are important. They include improved customer service and confidence, and the value of consumption information to customers and the utility. In an era of privatization and increasing competition in the utility industries, these intangible benefits, and the customer loyalty they create, are increasingly important.

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