A Current Study of Automatic Meter Reading Solutions via Power Line Communications

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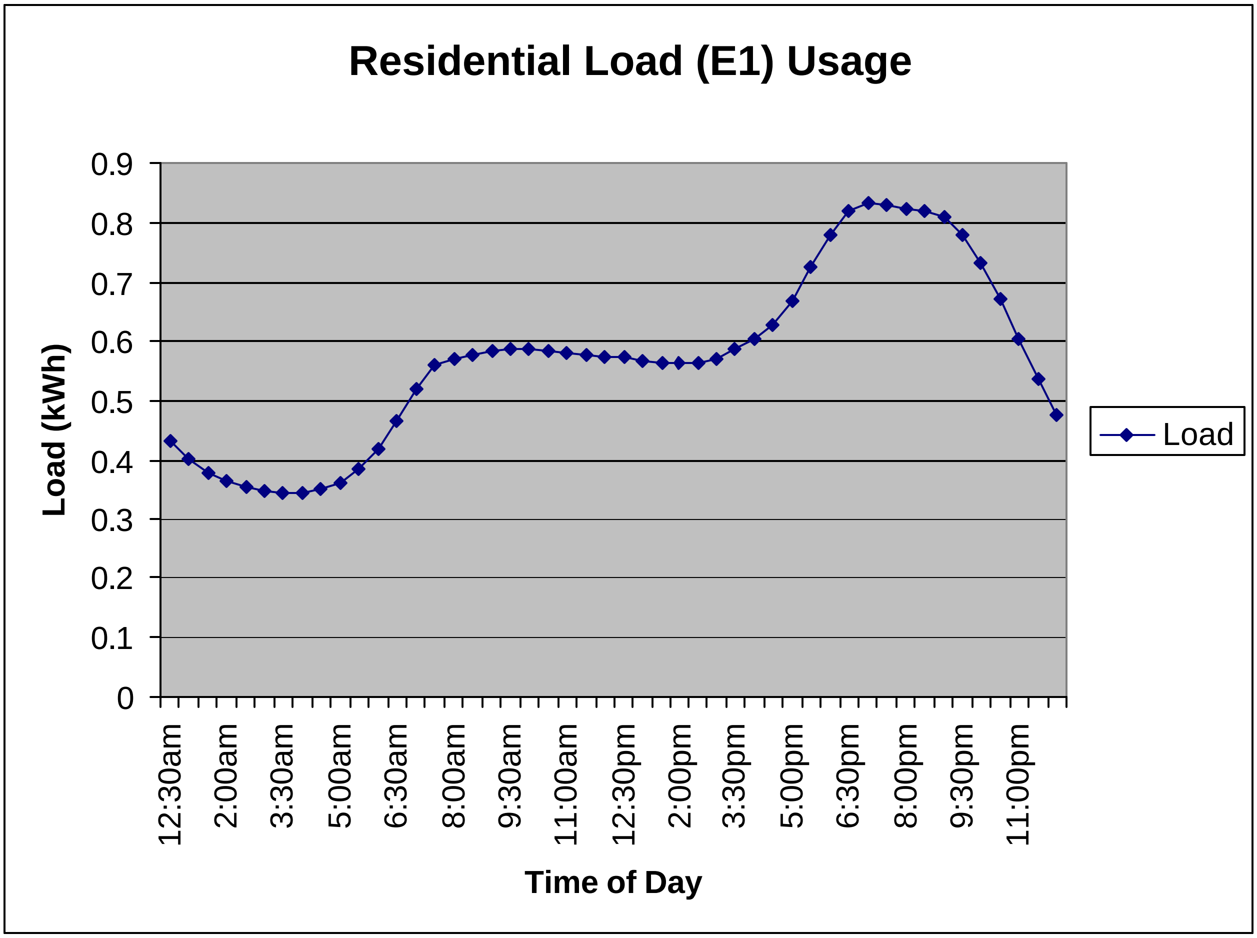
Abstract

It is more expensive to generate electricity during peak hours, yet consumers are not paying the more expensive rate for peak-hour electricity. It will be more economically efficient if consumers pay varying prices, depending on when they use electricity, instead of the current system where an average price rate is used. Hence we need to send real-time pricing to consumers. We look at current Automatic Meter Reading (AMR) solutions via Power Line Communications (PLC). If current AMR technology allows meter readings to be sent via power lines quickly and cheaply, then sending real-time pricing via power lines is feasible. In this study, we consider 3 companies that provide AMR solutions to existing customers, and make a comparison of their AMR technologies.

INTRODUCTION

Power demand from residents usually peak in the morning and at night, because residents usually switch on their appliances as they prepare for work in the morning, and when they come home from work at night. A typical resident's power usage profile is shown below[1]:

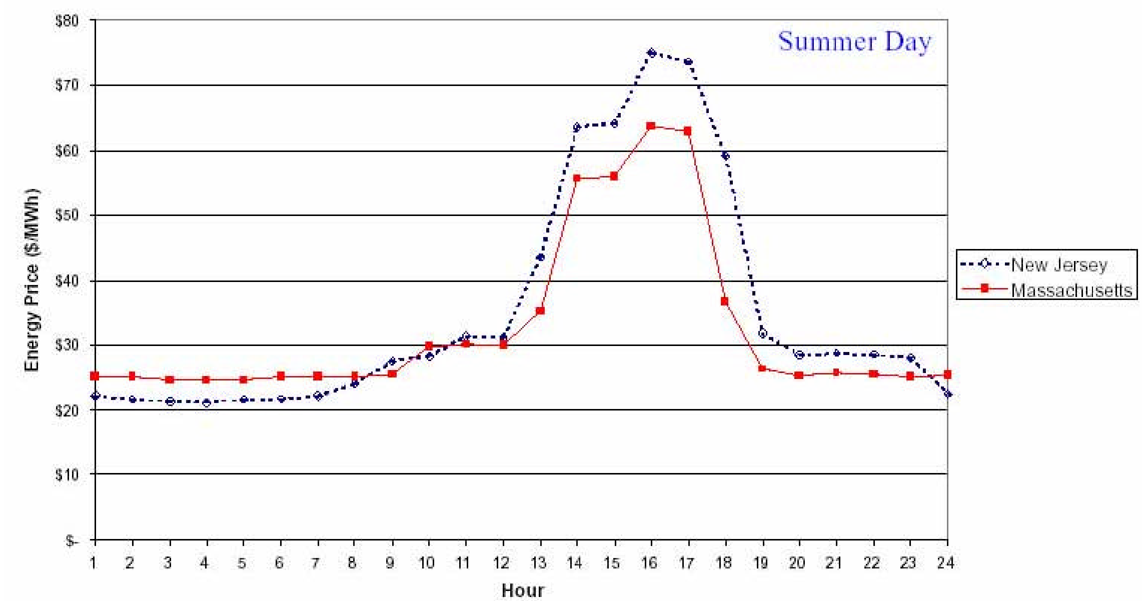


However, it is costly to generate electricity to match peak power demand. Additional plants have to be operated in order to increase supply. These plants only operate 200 out of 8760 hours per year hence maintenance of the plants make them economically inefficient. In addition, these plants generate electricity by using gas, which is more expensive. Also, labor during these peak periods is more expensive as well.

[1] Source: PG&E Corporation. 2003. Understanding Energy Use and Prices: Pacific Gas and Electric Company. Load Profiles (E-1, E-8, E-13)

Electricity costs vary substantially from hour to hour, often by a factor of five or more within a single day.

Typical Energy Price with respect to time of day



However, most customers buy electricity under time-invariant prices that are set months or years ahead of actual use. Customers should have the opportunity to see electricity prices that vary from hour to hour, reflecting price variations. Permitting and encouraging consumers to face time-varying electricity prices offers these benefits: economic, environmental, and reliability. Economic efficiency requires a range of customer choices. Offering customers a variety of pricing options is an essential component of competitive markets and a key to improving customer well-being. Customers who choose to face the volatility of electricity prices can lower their electricity bills in two ways. First, they provide their own insurance. Second, they can modify electricity usage in response to changing prices, increasing usage during low-price periods and cutting usage during high-price periods. Strategically timed demand reductions decrease the need to build new generation and transmission facilities. When demand responds to price, system load factors improve, increasing the utilization of existing generation and reducing the need to build new facilities.

Hence there is a need to send timely price signals to consumers. There are several ways to send this information. For example, power utilities may update prices on their internet web site. However, not all consumers will have internet access. Sending price signals via power lines to meters will provide the most extensive coverage of power consumers. Also, using power lines is a convenient and cheap solution.

Automatic Meter Reading (AMR) is the remote collection of consumption data from customers' utility meters using telephony, radio frequency, power lines and satellite communications technologies. AMR provides water, gas and electric utility-service companies the opportunity to increase operational efficiency, improve customer service, reduce data-collection costs and quickly gather critical information that provides insight to company decision-makers.

Since we are targeting to send price signals via power lines, we only look at technologies that provide AMR solutions through this medium. The data from customers' utility meters is similar in size with the data that contains price information. Therefore, analyzing current AMR solutions via power lines provides a realistic feasibility study of whether price signals can be sent to residents via power lines.

BACKGROUND INFORMATION

Power line communications (PLC) uses the power supply grid for communication. Power line networks have very extensive infrastructure in nearly each building. Hence, 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 this medium for data transmission, at high frequencies, presents some technically challenging problems. Apart from large attenuation, power line is one of the most electrically contaminated environments. This makes communication extremely difficult. Furthermore 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. Based on the voltage levels at which they transfer, power lines can be categorized as follows:

1. High-tension lines: These connect electricity generation stations to distribution stations. The voltage levels on these lines are typically in the order of hundreds of kilovolts and they run over distances of the order of tens of kilometers.

2. Medium-tension lines: These connect the distribution stations to pole mounted transformers. The voltage levels are of the order of a few kilovolts and they run over distances of the order of a few kilometers.

3. Low-tension lines: These connect pole-mounted transformers to individual households. The voltage levels on these lines are of the order of a few hundred volts and these run over distances of the order of a few hundred meters.

High-tension lines represent excellent carriers for RF energy as we only find open wire equipment with very few crossovers. A transmission power of about 10 watts is often sufficient to overcome distances of more than 500 kilometers. Around the year 1922 the first carrier frequency system (CFS) began to operate on high-tension lines in the frequency range of 15-1500 KHz. During the past and even nowadays the main purpose of CFS was to maintain the operability of the power supply. Through the application of modern digital modulation and coding schemes, a significant enhancement of bandwidth efficiency could be achieved for CFS.

Medium and low tension lines are characterized by large number of cross connections and different conductor types (e.g. open wire and cable). Long distance RF signal propagation is extremely bad in this environment because of high attenuation and impedance matching problems. Around the year 1930 ripple carrier signaling (RCS) began to operate on these lines. These used frequency range below 3 KHz down to 125 Hz with amplitude shift keying (ASK) modulation technique. The data rates achieved by RCS were of the order of a few bits per second. Load management and automatic reconfiguration of power distribution networks were among the most important tasks performed by RCS.

We see that the use of power line communications in the past was mainly for use by the Utility Corporations (UCs) in maintaining the seamless power supply. The UCs generally regarded the power distribution wiring as a "natural" medium for their communication needs, as all-important stations are connected. Recently, data communications over low-tension lines has gained a lot of attention. This is fuelled by the explosive growth of Internet along with advances in digital signal processing, error correction coding and electronic hardware. These helped in achieving medium to high bandwidth over low-tension power lines. However, these technologies are not able to transmit data through transformers, and are only able to provide “last-mile access”. Hence such technologies are more suitable for providing high bandwidth in local area networks, but unsuitable for our purpose.

Our goal is to send price signals, using power lines, from the utility company to the substations, which will transmit the signals to the electricity meters installed at residents’ houses. One of the criteria that we use to evaluate the PLC technologies that we have considered is whether signals are able to pass through transformers without much attenuation. We also look at the distance at which signals can be transmitted before degradation occurs. Ideally, the PLC technology should not require repeaters. If repeaters are required, then installation and maintenance cost will increase. The cost of the equipment that the technology requires is also a factor that we consider.

Lastly, the data transfer rate has to be fast enough to transmit a day's worth of hourly meter data in a day. We estimate the bandwidth that is necessary for price signals to be sent daily. We assume that TCP/IP protocol is used. Proprietary protocols that require smaller overheads can be used, but since TCP/IP overhead is fairly large, our estimate might be an overestimate – and it is better to overestimate than to underestimate. A typical TCP header size is 20 bytes (1 byte = 8 bits); a typical IP header size is 20 bytes; a typical Ethernet header size is 14 bytes; and CRC size is 4 bytes (16-bit CRC). We assume that the price is at most 200 cents. Hence the price needs only 8-bits (maximum integer that can be encoded with 8-bits is 256). Hence a data packet's size will be 60-bytes. Ideally, for real-time pricing, a price signal should be sent every 15-min. Hence the targeted bandwidth is approximately 0.5 bps[2].

However, day-ahead pricing can be done as well. Prices for each hour of the next day will be sent in 1 data packet. The new size of this packet is 106 bytes. This packet will be sent once every day. Hence the target bandwidth for hourly pricing sent daily is 9.8×10^{-3} bps[3].

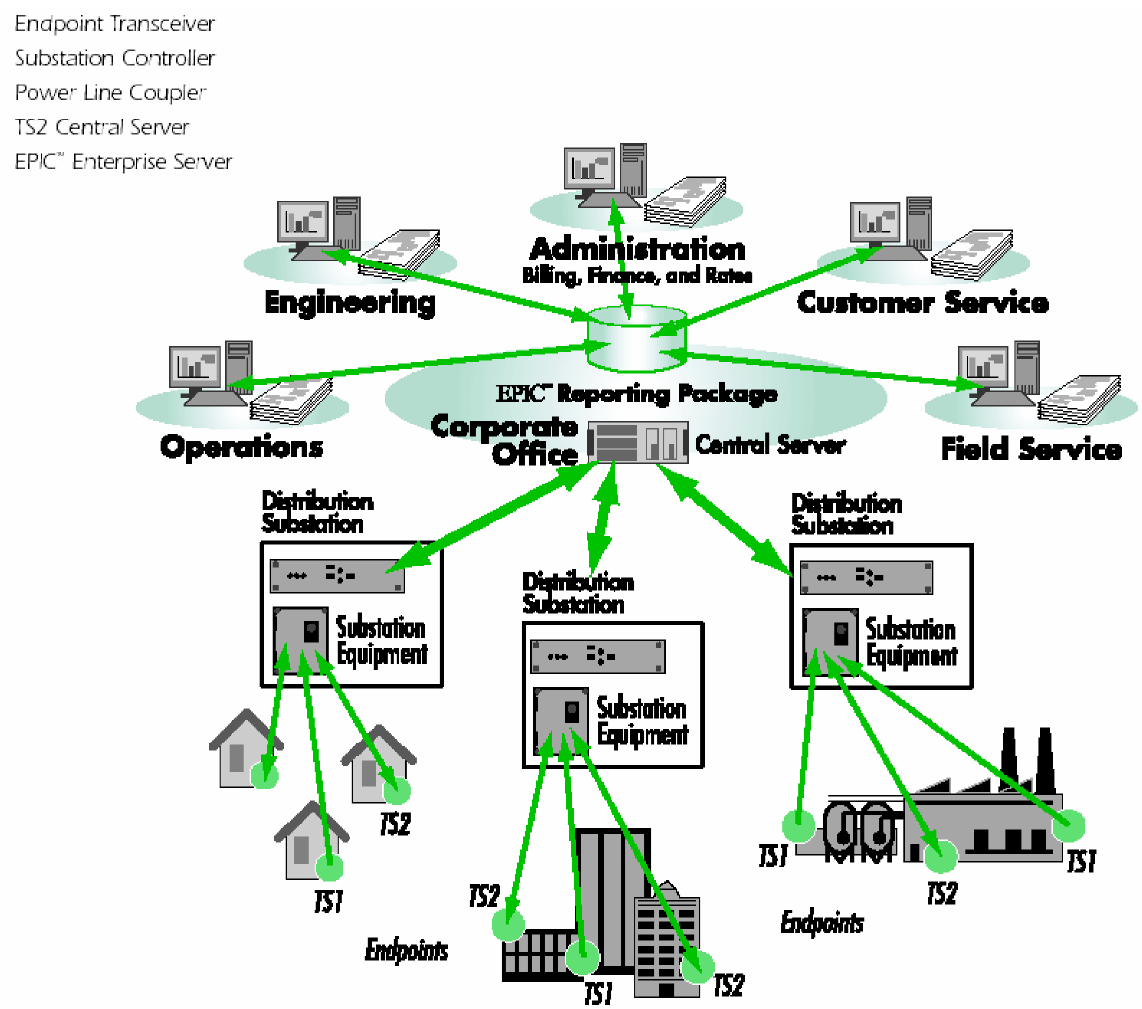
[2] Bandwidth = Data size / Time to transmit = 60 bytes / 15-min = 60*8 bits / (15*60sec) = 0.5 bps
[3] New packet size = Overhead + 24 prices = 20 (TCP) +20 (IP) + 14 (Ethernet) + 4 (CRC) + 24*2 (Price) bytes = 106 bytes. Bandwidth = 106*8 bits / (24*60*60sec) = 9.8×10^{-3} bps

TURTLE SYSTEMS

Hunt Technologies Inc.'s newest system, Turtle Systems 2 (TS2) is a two-way Automatic Meter Reading (AMR) system that allows command and control of endpoint specific data to a utility company. In this case, it can allow simultaneous transmission of meter readings from utility companies to meters and vice versa.

The TS2 system provides an infrastructure enabling delivery of meter readings to a specified control site, typically located at the utility office. Each TS2 transceiver has its own unique frequency allowing for every endpoint to transmit or receive continuously without threat of possible collision.

TS2 System Overview



(TS1 is their older one-way AMR system. EPIC™ is their hosting service)

The endpoint transceiver installed at each metering location stores energy usage and outage data and transmits daily time-stamped data packets over the power line to the Substation Controller to be downloaded by the TS2 Central Server. The endpoint is also capable of receiving commands from the TS2 Central Server via the Substation Controller. The transceiver's two-wire connection to line voltage provides both power and a communications path. Any future configuration can be performed remotely via the power line, eliminating trips to the field.

Each transceiver supports both demand and time-of-use rate structures as well as provides momentary and sustained outage information. This data collected by the endpoint transceivers is received daily where it is distributed throughout the utility company.

The Substation Controller is installed at the substation and facilitates bi-directional communication with both the Central Server at the utility office and the Endpoint Transceivers installed at the metering locations. The Substation Controller uses PLC technology to continuously receive data from each endpoint. In addition, the Substation Controller can send messages to each endpoint—broadcasting simultaneously to an individual endpoint, group of endpoints, or all endpoints. Since we want to send price signals to many meters at one time, this is an important feature that Turtle Systems fulfills.

The Substation Controller is built around an industrial grade computer designed to withstand the harsh environment of a substation. It consists of two main components: a substation processing unit (SPU) and an amplifier. The components are housed in a standard 19" rack and may be installed inside or outside of a control house. A Power Line Coupler is also installed at each distribution substation where it couples a low voltage signal onto the power line for communication with the endpoints. The Power Line Coupler consists of two main components: an impedance matching unit (IMU) and a standard two-bushing, three-phase power factor correction capacitor bank. The Power Line Coupler may be installed either inside or outside the substation fence.

As a customer has reported, the meters can be up to 160 miles away from the substation and yet be able to maintain data transmission. However, as its name reveals, the system is extremely slow. With regards to AMR, each data packet a meter reading, and is read once every 22 hours. The packet size is 63-bits, and takes 22 hours to transmit. This implies that the bandwidth of TS2 is around 8 x 10^{-4} bps.

Turtle Systems use ultra-narrow bandwidth (UNB). UNB power line carrier technology is a relatively new concept that has distinct advantages over other carrier systems. Signals in UNB systems have the long distance and reliability (increased noise immunity) virtues of low frequency signals used in ripple carrier systems, but UNB transmitters are inexpensive and can be built small enough to easily fit inside the average kWh meter. These meter reading devices don't have to be polled because each one is transmitting all the time. Similar to radio and television stations, each unit transmits on its own private frequency, and thousands of these transmitters can be sending signals up the power line simultaneously. However, if a single power disruption does occur, it will wipe out an entire data frame – up to 22 hours worth of data. Moreover, there is no way to request a fast re-send of the lost data frame; the re-send will take another 22 hours to transmit.

Each TS2 module costs $85, and the cost of equipment for a substation is around $25,000. Overall, Turtle Systems' TS2 has a fair advantage in terms of pricing, for each module. The distance of 160 mile, in which transmission can be done without degradation, is impressive. However, the cost of equipment for each substation is substantially higher compared to CannonTech's EMETCON system (as described in the next section). Also, the most significant disadvantage that TS2 has is its slow speed and its inability for a quick re-request of data in the case of data loss. This makes it seem unsuitable for our use of sending timely price signals to meters.

EMETCON DLC

DLC stands for Distribution Line Carrier, referring to the fact that this power line carrier system can communicate over utility-owned distribution power lines. EMETCON is an acronym for Electronic Metering and Control. The system is two-way, data-on-demand, with the ability to read a remote meter in around six seconds start-to-finish.

Besides its fast speed, EMETCON has a few other advantages. It has direct support for popular digital meters. Its software, Yukon Platform, allows data can be integrated to its other applications: Integrated Call Center, Load Response Center and Remote Power Factor Control. Also, its database is web-compatible and can be accessed via a web-display engine.

With EMETCON, the theoretical transmission rate is 72 Baud and the frequency is 12.5 KHz asynchronous. It takes between 3 and 6 seconds to read a meter, and thus to read and display real-time meter data every 15 minutes, the system would be limited to 180 meters per substation. This would be adequate for commercial and industrial sectors as seldom one will have that many meters per substation, and, especially since our system is deployed more by rural electrics rather than densely populated investor owned utilities (IOU) who normally would use a radio communication system.

EMETCON can store 48 intervals of data and the system can go around and collect that data, six pieces at a time, so the system then can do load survey on 6 times 180 meters per substation. The system at the utility company polls data, going out to the substation and requesting data to be returned. The substation equipment has intelligence to go out and read meters and store them until the communication line frees up to bring back data. Load survey reading of 6 15 minute intervals takes the same amount of time as reading one interval - 3 to 6 seconds per meter. If 30-minute interval data is requested instead, the number of meters per substation is increased to 6 times 360, and so the pipe expands. EMETCON does have repeaters available and injects the signal up to 34.5KV and it propagates well down through the distribution system, but the system does use capacitor blocking units to jumper the signal around grounded banks.

The data packet used for AMR is 52-bits long. Since the time taken for data to be transmitted from the substation to meter and back is 3 to 6 seconds, the bandwidth for this is approximately 17 bps. This is much less than the theoretical bandwidth of 72 baud.

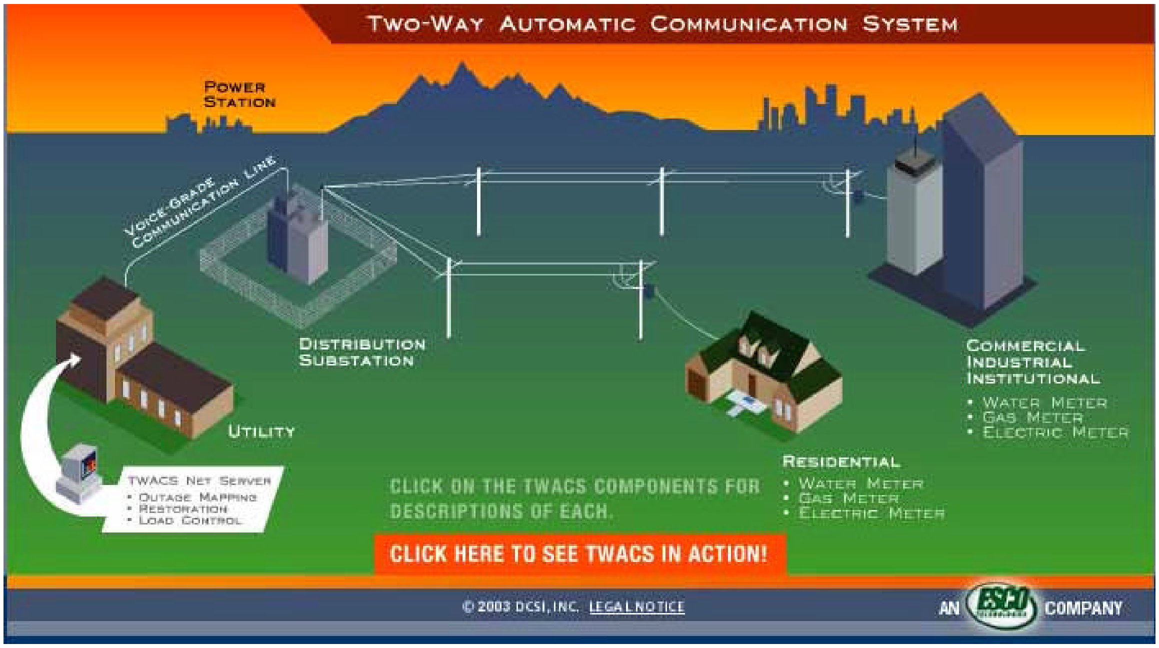
The all-in cost of EMETCON system is approximately $175 per meter. Hence the per-meter cost is fairly high. The cost of equipment needed per substation is between $12,000 and $15,000, depending on options, volume, etc. This is significantly cheaper than the per-substation cost of Turtle Systems.

The longest distance that meters can be from is 100 miles. In addition, EMETCON AMR can be installed with fixed network architecture, or can be used as a portable system for hard-to-read meters and tough-terrain routes. Hence the technology is very popular in mountainous and rural areas. EMETCON is widely used by rural electrics where commercial data networks are non-existent. Coverage includes large parts of rural Nebraska, Kansas, Colorado, Missouri, Oklahoma, Texas, New Mexico, Michigan, Iowa, Maryland, and Delaware. Clients include over 120 rural co-ops and municipals. EMETCON seems to be used widely for rural areas but not city areas.

TWACS® SYSTEM

Since 1978, Distribution Control Systems, Inc. (DCSI) has marketed and manufactured the highly successful, field-proven TWACS® two-way power line communication technology which provides unique capabilities ideally suited for Automatic Meter Reading (AMR), load control, distribution automation and other value-adding services. TWACS is a fixed network utility communication system that uses patented technology to communicate over electric power lines, providing low-cost, highly-reliable, two-way communication between the utility and the consumers of electricity, water and gas. To date, DCSI has in excess of 2 million endpoints under contract, including the industry's largest fully operational two-way deployments. All of these systems provide immediate, two-way access directly to each end-point device through the TWACS power line fixed network. The TWACS technology delivers over 99% message reliability, which results in highly efficient and dependable AMR demand-side management and distribution automation systems.

TWACS® System Overview



Unlike conventional power line carrier systems, which superimpose a high frequency on the power lines, TWACS works by modulating the voltage waveform at the zero-crossing point. The result is a communication system that uses the Utility's network at the frequency for which it was designed and built. The TWACS communication channel is power lines used at 60 Hz. Because the TWACS communication signal is part of the AC waveform, there is no need for repeaters, blocking devices nor any conditioning or special maintenance of the utility's distribution feeders for TWACS to achieve high reliability. The only equipment needed is a module that fits within the meter at a home or business and transmitting/receiving equipment that is installed within a utility's fenced-in substation. This is because it uses 60Hz as the actual carrier rather than a superimposed high frequency carrier. Use of such superimposed high frequency carriers leads to short propagation distances, loss of signals at capacitors and underground line segments, standing waves/nulls, etc. hence the need for repeaters and blocking devices for traditional power line carriers. The TWACS system has none of the above deficits. By far, TWACS is the only company that has figured out how to do this effectively and reliably.

There are a few other advantages of TWACS provides its customers. Firstly, utility companies already own the data transmission infrastructure. Owning the TWACS power line communication network provides multiple competitive advantages. TWACS allows you to manage your data collection process and control critical interval data. You are able to reduce risk by not depending on a third party's proprietary system to carry the data or this party's ability to provide the type of data you need when you need it.

Secondly, TWACS has nearly 100% service territory coverage [4]. TWACS achieves the highest coverage in the industry, particularly for geographically diverse utilities. Since the utility's existing power lines are used "as is," coverage exists virtually everywhere the power flows. Homogeneous levels of service can be implemented throughout a utility's territory. Whether it is immediate on-request reads, daily or hourly interval data, load control or service connect/disconnects, all of the rich features of TWACS are available in urban, suburban and rural areas. TWACS provides an equally compelling business case in all customer densities. This is due to the use of existing power lines rather than an infrastructure where cost per metered point rises sharply as customer density declines or a service where coverage is not available at all premises. TWACS is only incrementally higher in cost in rural areas as compared to urban areas, but so is the meter reading process. In urban areas, large substations serve 10,000 or more

[4] The few exceptions relate to high-end transmission-served customers, which frequently have AMR capability in place and PT-rated services where promising progress has been made toward TWACS solutions for this small but important segment of a utility's meter population. Note that CT-rated services are routine TWACS applications.

consumers, allowing TWACS to achieve the industry's lowest per-meter network cost structure. TWACS' relatively uniform per-meter cost structure allows a utility to choose a deployment strategy that fits their unique business needs.

Regarding transformers, DCSI has at least one example where the TWACS system was installed at 34.5kv/19.9kV (L-L/L-N voltages) and passed through several intermediate 12.47kV/7.2kV substations, and then through a 4.16kV substation and finally to a 120/240V conventional single-phase residence. This example is about as complex as the North American distribution system, yet the TWACS signal was unimpaired by these transformations. Also, TWACS signals can pass through circuit breakers, unlike the old X-10 technology which bypassed them. In addition, the longest circuit proven so far is 85 linear miles with no degradation noted.

TWACS is able to collect data at interval lengths as short as 15-minutes and retrieve and store it within the TWACS Net Server for daily delivery. TWACS load control capabilities include load status verification and automatic grouping of loads for measuring load management effectiveness. Load control data can be used for load forecasting and pricing. Load profiling allows for retrievable billing for direct access tariffs. Because TWACS is a true two-way system, peak demand can be recorded and reset remotely.

The data packet used for AMR is 8 to 15 bytes long. A two-way transaction takes 8.8 seconds, round trip, to communicate with a single meter. This is called a "serial number mode" request in that a single end-point is polled. Of the 8.8 seconds, about half is on the "outbound" channel – from the substation to the end-point, and the other half is on the "inbound channel" – from the end-point to the substation. In group mode, the system can perform 16 inbounds for each outbound with all 16 units communicating in a 22-25 second period. Additionally, all three phases can be running nearly concurrently, adding to parallelism inherent in the electric distribution network. With all of these features, the average time per meter falls to below one second. The system can also "broadcast" an outbound, one-way message to all end-points in less than a minute containing a data payload of a dozen or so bytes. Hence, the speed at which a substation can transmit data to meters is approximately 30 bps[5], and with parallelism, the speed at which meters can send data back to substation is approximately 80 bps[6].

Since a TWACS system transaction only lasts 8.8 seconds, it is not an issue if it is destroyed by a noise burst since it is automatically re-tried seconds later. So, in terms of usable channel latency and throughput, the TWACS system outperforms both EMETCON and Turtle Systems' TS2 because it is optimized to expect a certain number of noise hits (up to 5% of messages may be damaged on some noisy systems, though most systems average close to 99% first try success) and to overcome them with ease.

The all-in cost of TWACS system is approximately $125 per meter. This pricing is reasonable. Although TWACS has the shortest distance (85 miles) in which the signal can be transmitted without degradation, this is adequate for accessing rural areas. Being able to pass through transformers without impairing the signal and not needing repeaters is also another big advantage of the TWACS system. The transmission speed of TWACS is also the highest amongst the 3 systems being compared. Lastly, TWACS has been implemented for approximately 25 years and has over 100 customers to date. Hence has a rich experience in this aspect.

All in all, with its speed, robustness, reliability, and even pricing, TWACS is by far the best choice that we have. Indeed, the TWACS system might be able to provide real-time or day-ahead pricing to residents via power lines.

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[5] Data packet = 15 bytes; Time taken = 8.8 sec round trip -> one way takes 4.4 sec.
Bandwidth = (15*8)bits / 4.4 sec = 30 bps

[6] Data packet = 16 channels * 15 bytes; Time = 25 second. Bandwidth = 16*15*8 bits / 25 sec = 80 bps

CONCLUSION

Having compared the 3 current AMR technologies, we have found that there exists one that seems able to support sending real-time or day-ahead pricing to consumers. The TWACS system has excelled in terms of speed and robustness and has extensive coverage and experience in this field. With this technology that can send price signals to consumers, our next goal is to investigate what we can achieve with real-time pricing sent to meters of residents.

It is unrealistic to expect residents to monitor power prices every hour. If day-ahead prices are sent to residents, then they can plan their activities and hence change the timing of their power usage, according to the given prices. For example if a resident usually does laundry in a peak period, then the resident might decide that it does not really matter if he/she did the laundry at an off-peak period. Alternatively, appliances can be programmed to automatically poll the meter for price information, and switch to power-saving mode or switch off completely if a certain price level is exceeded. For example, we might program the refrigerator to operate similarly to existing Honeywell thermostats – if the price exceeds a certain level, then it will switch to a power-saving mode and not operate at 100%.

Hence we will be able to shift peak usage to off peak periods, reducing the demand peak-hour electricity. However, it is important to note that if everyone shifts their usage schedule from peak periods to off-peak periods, then there will be a sharp change in demand. The electricity demand might fall drastically during peak periods and rise during off-peak periods. A sudden change of demand might make the grid unstable. Hence an autonomous agent might be used to regulate power demand.

Next, we will like to create a simulation that investigates the possibility of appliances polling the meter for price information and adjusting its operation with this price information.

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