Conf-941218--9

PNL-SA-23974

ADVANCED METERING TECHNIQUES IN THE FEDERAL SECTOR

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December 1994

Presented at the
World Energy Engineering Congress Conference
December, 7-9, 1994
Atlanta, Georgia

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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MASTER

ADVANCED METERING TECHNIQUES IN THE FEDERAL SECTOR

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ABSTRACT
The lack of utility metering in the federal sector has hampered introduction of direct billing of individual activities at most military installations. Direct billing will produce accountability for the amount of energy used and is a positive step toward self-directed energy conservation. For many installations, automatic meter reading (AMR) is a cost-effective way to increase the number of meters while reducing labor requirements and providing energy conservation analysis capabilities. The communications technology used by some of the AMR systems provides other demand-side management (DSM) capabilities. This paper summarizes the characteristics and relative merits of several AMR/DSM technologies that may be appropriate for the federal sector. A case study of an AMR system being installed at Fort Irwin, California, describes a cost-effective two-way radio communication system used for meter reading and load control.

INTRODUCTION

The overwhelming majority of utility meters are still read visually and the readings manually recorded in a meter book by a person who walks a route, just as when the meters were introduced a hundred years ago. Advanced metering techniques provide an opportunity to totally redesign conventional revenue billing, load evaluation, load control, and customer relations processes. Automatic meter reading (AMR) allows a variety of rate structures and provides more detailed load and power quality evaluations. Load control functions allow intelligent demand-side management (DSM) with feedback (two-way communications). These two capabilities, which previously required separate, dedicated, and expensive systems, can now be integrated through the use of a common communications network.

With millions of square feet of buildings, utility bills to match, and a mandate to reduce energy usage to 80% of the 1985 baseline by the year 2000, the federal sector is an ideal candidate for AMR/DSM systems. Unfortunately, utility meters at federal facilities are almost nonexistent. The utilities are metered at a single entry point for billing purposes and at a limited number of locations for chargeable activities located within a facility. For a typical facility, less than 10% of the utilities at individual buildings are metered. In cases where meters exist, the meters are not read routinely because of manpower shortages. Estimating energy consumption is common. There is also a special problem for installation of most commercial AMR equipment, which were designed as socket-mount meter replacements. The designs will have to be modified to be cost-effective in widespread applications at federal facilities.

This paper summarizes the operating characteristics and relative merits of all the major AMR system technologies in use today. Each technology excels in one or more areas, resulting in no single "best" AMR system for all applications. With this background, an AMR/DSM system that meets specified technical, administrative, and economic requirements was selected for Fort Irwin, California. The AMR capability will allow the Directorate of Public Works to accurately bill all chargeable activities on base. Direct billing for utility consumption and demand will be a significant step toward self-directed energy conservation. The DSM capability will allow integrated load control of air conditioners and other selected loads. An innovative electric utility service is being used for capital equipment financing and long-term system maintenance. Cost-effectiveness of the

AMR/DSM system, based on savings of manpower, energy consumption, and demand, is presented.

DESCRIPTION OF AMR SYSTEMS

One representation of the hierarchy of metering techniques is graphically presented in Figure 1 [1]. Many utilities considered these five metering categories as a very practical migration strategy for ramping up from handheld computers to fully automatic meter reading. Short descriptions of the five metering categories follow.

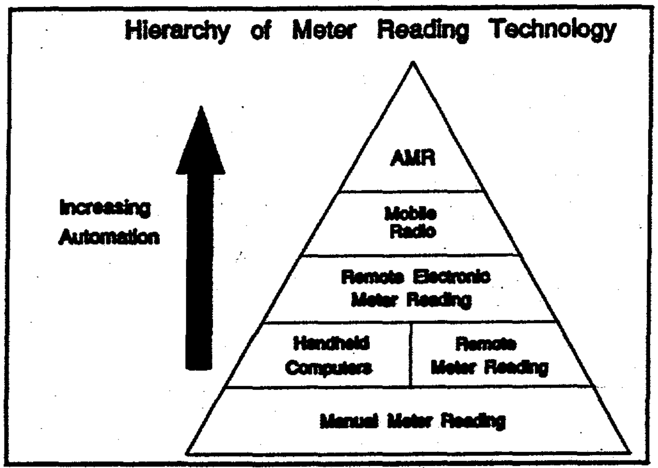

Figure 1. The base width of the triangle indicates that the number of units in service decreases as cost and functional features increase with increasing automation.

Manual Meter Reading: A meter reader uses a route book and manually records the meter readings. A clerk manually calculates consumption and manually prepares the bill. Computers have been introduced to accelerate the basic billing process and reduce clerical errors, but the basic process has not changed in a hundred years.

Handheld Computers: Meter readers enter a visually read meter reading directly into a handheld device. Although the handheld device does not obtain the reading automatically, this simple step dramatically improves clerical accuracy in the billing stages. Some handheld devices are "smart" enough to display routing and special meter information (e.g., Under Deck; Beware of Bad Dog) and notify the meter reader if the new reading is out of range, indicating a possible error.

Handheld computers are often complemented by reading a second register or receptacle linked to a nearby meter, called remote meter reading (RMR). This is particularly important for meters that are physically hard to access due to installation in basements, behind locked gates, or near bad dogs. *Handheld computers*, with *remote meter reading* and *remote electronic meter reading*, introduced automation into the meter reading and billing process, plus access to hard-to-read meters. But these systems still require a person to physically contact each meter or a receptacle linked to a nearby meter.

Remote Electronic Meter Reading: When RMR is combined with an electronic data transfer technology, the meter reading can be automatically read by the handheld device. Remote electronic meter reading still requires physical contact between the handheld device and the meter or a receptacle linked to a nearby meter, but it completely eliminates the errors associated with a visual read and manual data entry.

Mobile Radio Meter Reading: The meter reader need only come within close proximity of the customer premises. Radio frequency communication is used to send a signal to "wake up" the transmitter located at the meter, which will then send its reading to the receiver. The receiver can be either a vehicle-based computer or a handheld device. Mobile radio systems reduce labor requirements and read errors by communicating directly between a meter and a handheld or van-based computer. Mobile radio systems have the largest number of installed units and have the highest acceptance by commercial utilities. However, they are limited with regard to meter reading frequency (scheduled monthly reads only) and other advanced metering features.

Automatic Meter Reading (AMR): Fully automatic meter reading refers to requesting and receiving meter reading information from a central location via telephone line, radio frequency, power line carrier (PLC), or cable TV. All meter reads are automatically handled by a computerized system instead of a person visiting each meter location. The communications technology used for these AMR system defines both immediate capabilities and future expansion of both number of sites and new capabilities.

Selecting an AMR system that is appropriate for an individual application involves assessing the ability of each AMR technology to meet a set of unique requirements. Issues such as cost, level of maintenance, and the availability of features must be balanced to select the proper system. Integration of DSM capabilities with the AMR capabilities is a unique challenge. The following section discusses the capabilities of commercially available advanced metering equipment. The discussion of capabilities and the selection criteria are taken from [2].

Communications Technologies
A detailed study of the available AMR technologies showed a wide range of technologies from simple to very complex. The more complex systems, although more expensive, provide more value to the utility through advanced features. The following is a list of technologies that are options for AMR systems:

•*Dial-in telephone* system meters are programmed to periodically call the central station by using a shared customer telephone line. The central station cannot contact the meter without ringing the customer's telephone. This system raises some privacy issues and limits the meter reading frequency and other advanced metering features requiring communications initiated by the central station.

•*Conventional dial-out telephone* systems with dedicated leased telephone lines are probably the least expensive form of an unrestricted full-time two-way communications AMR system for a limited number of special customers. Special customers include those with very hard-to-read meters or unique metering requirements (large customers). Some dedicated lines can be avoided by using automatic line-share switches, which connect a shared line to a meter without ringing the customer's telephone.

•*No-ring dial-out telephone* systems will be required for expansion to a large set of customers. The no-ring dial-out telephone system is dependent on the cooperation of the telephone operating company for access, installation of special equipment at the telephone switch station, and reasonable tariffs. Telephone number management has proven to be a difficult problem for large systems.

•*Distribution line carrier* (DLC) systems perform well for high-density electric metering and DSM load control. These systems are independent of the telephone companies and radio frequency availability problems. But, they may be prohibitively expensive for very low density metering and may be unavailable for some gas and water metering.

Distribution line carrier systems use two competing technologies, both of which require significant equipment at each electric distribution transformer station. The first injects a high-frequency signal onto the 60-Hz power distribution system. Communication signal attenuation problems will require additional field equipment to handle problem transformers, capacitors, underground lines, and feeder switching. The second technology uses a power frequency modulation technique, which imposes a zero-crossing shift independently on each phase of the power distribution system. This technique will successfully penetrate all distribution system equipment without any modification or tuning. That is a significant installation and long-term operation advantage.

•*Long-range radio*, configured as cellular nodes or central broadcast towers, can offer the largest range of near real-time meter reading for large metering systems. This is the only technology that can provide unrestricted high-speed two-way communication with each individual meter of a large system, which may be necessary for additional services such as security, energy management, or customer information. However, the radio equipment required for complete coverage of a large service territory, and its maintenance, is the most expensive of all the systems. A major concern in siting a long-range radio system is Federal Communications Commission (FCC) licensing, which may be difficult at federal installations that have already allocated a large portion of the available frequencies.

•*Packet radio systems* provide two-way communications through the use of radio frequency for wide-area communications and power line carrier for local-area communications. The radio frequency transceivers are a low-power, spread-spectrum technology that operates in the range of 902 to 928 MHz. The FCC allows this type of low-power radio operation without individual site licensing, which is a major advantage over long range radio systems. The associated disadvantage is a limited transmission range of under 2 miles, depending on terrain. Radios are typically mounted on a street light pole and can communicate via power line carrier with any meter or load control device on the same secondary.

Commands or data are automatically bundled into secure packets and routed to the destination, which normally requires "hopping" through multiple radios. Messages that require six hops round trip might take 20 seconds for a response. Transmission of high-priority messages can be expedited and local intelligence can provide unsolicited reporting by exception. This combination provides system response times that are more than adequate for AMR and DSM applications.

Summary of Capabilities
A comparison of all the commercially available advanced metering technologies is presented in Table 1. This is a general comparison of the applicability of the technology types to various meter density/terrain installation conditions, utility rate structures, data collection frequencies, and additional services.

Table 1. Advanced Metering Technology Screening Matrix
(✓ = Good, ▲ = Fair, ○ = Poor)

	Manual Meter Reading			Automatic Meter Reading			
Technology ▸	Handheld Computers	Remote Meter Reading	Mobile Radio Meter Reading	Dial-In Telephone[1]	Dial-Out Telephone[1]	Distribution Line Carrier[2]	Long-Range Radio[3]
Meter Density/Terrain							
High Density	✓	✓	✓	▲	✓	✓	✓
Low Density	✓	✓	▲	✓	○	▲	○
Hilly	▲	▲	▲	✓	✓	✓	▲
Rate Structure/Data Collection Frequency							
Monthly Read	✓	✓	✓	✓	✓	✓	✓
Daily Read	○	○	○	✓	✓	✓	✓
Time-of-Use	○	✓	✓	✓	✓	✓	✓
Demand	✓	✓	✓	✓	✓	✓	✓
Profile, Volt, Amp, PF	○	✓	✓	✓	✓	✓	✓
Read-on-Demand	○	○	○	○	▲	✓	✓
Real-Time Data Display	○	○	○	○	▲	▲	▲
Additional Services							
Load Control	○	○	○	○	▲	✓	✓
Security	○	○	○	▲	▲	✓	✓
Energy Management	○	○	○	○	▲	✓	✓
Customer Information	○	○	○	○	▲	✓	✓
Estimated Equipment Cost							
200 Meter System	$10-20K	$25-50K	$75-100K	$100-150K	$175-225K	$250-300K	$300-400K

Notes: 1) Telephone systems will work with either standard land lines or cellular telephones.
2) Distribution line carrier (DLC) systems refer to both high-frequency injection power line carrier and zero-crossing shift technologies that communicate using the electric utility's power distribution system.
3) Long-range radio includes central, cellular, and distributed (packet radio) systems. Some are hybrid systems that use a short-range power line carrier to communicate between the meter and the radio transceiver.

The estimated equipment cost for a generic 200-meter system for each technology is also listed in Table 1. Note that this is for meter reading only, does not include installation labor or special application software, and assumes that standard utility meters are already installed and will be converted for use with the system. Because most federal facilities have very few existing meters, a significant additional cost may be associated with initial installation of basic metering equipment before an AMR system can begin to operate.

To date, most of the AMR system installations have been trials and demonstrations. Very few utilities have committed to full-scale implementation of AMR. The reasons include 1) rapidly evolving technologies, 2) lack of standardization between vendors, resulting in single-source dependence, 3) relatively high equipment costs, and 4) a very conservative approach toward large-scale changes in existing proven meter-reading practices. Mobile radio technology is the smallest change from existing meter reading practice, costs the least, and has the largest installed base. But mobile radio meter reading technology still requires periodic field visits for meter reading, typically as a vehicle-based meter reader system, and is limited to traditional monthly meter reads.

A CASE STUDY: FORT IRWIN, CALIFORNIA

Fort Irwin is planning to go to a Directorate of Public Works (DPW) model for all utility services, with each activity on base eventually becoming a "reimbursable" customer. Energy conservation will be an important factor. This is a relatively new concept for U.S. Army Forces Command (FORSCOM) military bases and will require several years for complete implementation. Discussions with Fort Irwin and FORSCOM staff reveal that the two most important goals for an AMR system are reduction of manual meter reading costs and reduction of utility bills. To make the DPW model fully functional, each customer's utilities must be metered so that the billing accurately represents consumption and energy conservation activities. Estimated utilities bills will no longer be acceptable. Because metering and billing have not been a widespread historical requirement, existing meter installations and billing processes are not sufficient for the new DPW role.

While metering alone will not affect consumption or demand of any utility, metering used in combination with the DPW model can influence the consumers of the utilities to reduce their usage. This is accomplished by simply passing on actual cost savings to the consumers. As consumption, demand, and unit costs for utilities go up, the customer is notified via the next bill. This typically leads to increased consumer awareness and increased energy conservation activities, without any organized energy conservation programs. Metering can also be used as a maintenance and trouble-shooting tool to help identify buildings where demand and consumption are higher than expected.

Meter Reading and Utility Costs

Fort Irwin is charged approximately $40,000 per year by the site maintenance contractor for staffing the meter reading service. In addition, a significant amount of the utility billing coordinator's time is spent dealing with customer complaints about misread meters and incomplete or incorrect readings. A quick check of several months of meter readings reveals several zero- or negative-consumption meters each month, indicating unexpected faulty meters or inaccurate readings. Extrapolation of these high costs to the ten- to twenty-fold increase in the number of meters required for a full DPW model quickly reveals that a more efficient method for collecting accurate meter readings is required.

Fort Irwin and FORSCOM are also interested in reducing utility bills to meet the federally mandated energy conservation goals and to make more efficient use of a limited utilities budget. Because all utility bills are paid at the command level, reducing utility bills is FORSCOM's main objective. In general, reducing electric consumption, electric demand, natural gas consumption and water consumption are all important. Appropriate metering can quantify the consumption and demand profiles of each utility at each building, allowing the DPW staff to identify and correct excessive utility consumption or demand.

Under the current electric rate structure, reducing the demand for electricity is not a high priority at Fort Irwin. This rate structure includes an incremental usage clause that does not apply the full Southern California Edison (SCE) demand charge. The incremental peak kilowatt charge is equivalent to SCE's Avoided Capacity Cost and was only $2.54 per peak kilowatt in August 1992. However, a rate change expected for 1997 will increase the full peak kilowatt charge to $18.90 per peak kilowatt in the summer. The new demand charge rates will make load control an attractive option.

For SCE, reducing the demand for electricity is a very high priority. One reason for this priority is that Fort Irwin is at the end of one of SCE's distribution lines, which are already near capacity, and Fort Irwin is continuing to expand. Construction of a new electrical service through 30 miles of endangered desert tortoise habitat would be extremely expensive.

Fuel Leak Alarm Display
Motivated by $1.2 million in fuel leak cleanup costs during the first seven months of FY 1993, Fort Irwin asked that PNL evaluate the feasibility of using an AMR system for monitoring and reporting fuel leak alarms. Fort Irwin staff believe that the existing fuel tank leak alarm systems, which display only in a building near the tank, are being reset, turned off, or ignored too often. The resulting delay in leak detection has caused minor problems to grow into major cleanup efforts.

A preliminary evaluation, based on limited details of the leak alarm systems and locations, revealed the following:

- Alarm capabilities that are near-real-time are available with AMR technologies.

- The costs for connecting a leak alarm to the AMR system are minimal, assuming that the alarm system has a standard electric signal and is located in a building already being metered for electricity.

- A conservative assumption is that $50K/yr in fuel leak cleanup could be saved by having a centralized alarm display system.

For both existing fuel tank leak alarms and any future fuel line leak alarms, a centralized alarm display would improve response to the leak alarms and reduce cleanup costs. This alarm display capability could also be extended to other services, such water reservoir tank levels, water well pumps, or security systems.

AMR/DSM System Selection
The near-term requirements of the AMR/DSM system are designed to maximize cost savings by 1) eliminating the manual meter reader service and improving meter reading accuracy, and 2) automating electric load control for demand charge reduction. The long-term requirements include the capability for 1) automating the utility billing process, 2) conducting building performance evaluation and prioritization, and 3) displaying near-real-time alarms for fuel leak detection or water reservoirs.

Based on these requirements, all forms of advanced meter reading at the mobile radio sophistication level or less are ruled out (see Figure 1). While technologies such as remote electronic reading, remote meter reading, and handheld computers offer increased meter reading accuracy, they do not reduce manpower requirements significantly from the levels required for manual meter reading. Nor do these technologies offer any means for advanced capabilities such as load control or demand profile recording.

Beyond mobile radio in terms of sophistication are a number of AMR systems that are fully automated. These systems are characterized by the ability to read and control meters from a desktop personal computer or workstation. These systems are typically capable of advanced AMR/DSM capabilities.

The main distinction between systems is their communication technology. There must be a link between the meters in the field and the computer in the billing office. That link may be a telephone line, a radio signal, cable TV line, electric distribution line, or a hybrid using some combination links. For Fort Irwin and most other military installations, telephone-based systems can be ruled out because 1) extra telephone lines are typically in short supply, 2) Fort Irwin does not own and operate its telephone switch station, and 3) installation of new phone lines, management of phone numbers databases, and maintenance of phone systems has proven to be extremely labor-intensive.

Elimination of telephone lines leaves radio, hybrid systems, and DLCs for further consideration. In a typical radio-based AMR system, radio-equipped meters communicate with the central computer through a central radio receiver. While the system is conceptually simple, costs for high-quality radio equipment are quite high. The relatively simple FM radio systems typically used for load control are not capable of the two-way communications required for meter reading. An additional complication is the need for FCC licensing. On the basis of the cost and licensing requirements, conventional central radio-based systems were also eliminated.

One radio-based system that cannot be eliminated is a hybrid power line carrier/packet radio network system referred to in this paper as simply a packet radio system. The system uses low transmitting power, spread-spectrum packet-switched radios operating in the 902- to 928-MHz band. The radios are typically installed and powered on distribution transformers' low-voltage secondaries, the same power lines that serve the customers. One radio and all the meters served by one distribution transformer form a local area network and communicate with one another over the secondaries using power line carrier communications. Multiple radios form a wide area network to move packets over longer distances within a utility service area. This system does not require FCC licensing. The use of a single radio transceiver for multiple meters can also keep costs down in some applications. Southern California Edison has proposed installation of this type of AMR system as a service that can be offered to Fort Irwin under the existing utility contract.

The final option is a two-way communications system DLC technology. One system uses a unique power frequency modulation technology (zero-crossing phase shift) for both outbound and inbound communications. The technology can propagate across any transformer winding configuration without conditioning and can communicate simultaneously on each phase with better than 99% first-try success. Unlike other DLC systems that inject a high-frequency carrier on the power distribution system, this one does not require network conditioning devices, capacitor isolation units, or repeaters, and is unaffected by distribution system dynamics. Communication from the master station to the distribution substation is via a dedicated telephone line. Initial costs for the electric substation equipment may be high for such a system, but incremental costs for additional meters are relatively low.

The two AMR/DSM technologies selected for further evaluation are a packet radio system and a two-way communications DLC (using zero-crossing phase shift technology) system. Both systems have the required AMR/DSM capabilities. A preliminary economic cost analysis indicates that the DLC has a lower life-cycle cost.

Financing Option

Southern California Edison, the utility providing electricity to Fort Irwin, has offered a complete AMR/DSM system service. SCE's choice for AMR/DSM system technology is the NetComm packet radio technology manufactured by Metricom. SCE's service will provide all the up-front financing, design, equipment selection, contractor selection, installation, training, and long-term maintenance. Fort Irwin staff would maintain day-to-day operation. SCE has technical and field experience with the Metricom packet radio system because of SCE's role in the technology development, several small-scale demonstration projects, and a large-scale distribution automation project.

This is a unique opportunity for Fort Irwin for two reasons. Fort Irwin and FORSCOM would not have to work through the two- or more-year process of requesting a federal budget appropriation for the up-front capital financing. Perhaps even more important, long-term operation is guaranteed because SCE would have total maintenance responsibility. The importance of this long-term maintenance cannot be over-emphasized; a large number of automation systems installed without long-term maintenance support and quickly have become unusable and disconnected.

However, there is no free lunch. SCE's AMR/DSM system service will cost Fort Irwin approximately 1.7% of the installed cost per month for 20 years. Early termination would cost Fort Irwin a lump sum payment for the remaining investment. Note that although this 20%/yr payment may seem high, it includes both scheduled and unscheduled maintenance and relevant product upgrades, which Fort Irwin would have to purchase even if the AMR/DSM project were fully funded by the government.

SCE's AMR/DSM service requires the use of the Metricom packet radio system. Although the two-way communications system DLC has a lower estimated life-cycle cost, the SCE service is the only way to package design, installation, and long-term maintenance in a single contract that does not require up-front government financing. The AMR/DSM system will be installed two years sooner, with two additional years of energy savings, than if government financing were requested. With limited funding available, there is no guarantee that government financing could be obtained at all.

AIR-CONDITIONER LOAD CONTROL

Demand-side management capabilities at Fort Irwin, installed as part of an automated meter reading system, will provide demand and consumption savings through peak demand reduction and off-hours equipment shutdown. The AMR/DSM system will be capable of monitoring base total and selected individual building electric demands and environmental conditions (e.g., air temperature), determine when load control threshold conditions are exceeded, and automatically turn off a prioritized list of loads in a cyclic pattern. The goal of load control is to reduce the monthly peak demand during the summer peaking months and the associated charges. A secondary benefit is some reduced electric consumption.

Automated load control is important because the single highest peak demand for the month determines that month's demand charge, and 50% of the demand carries over into the following 12 months (ratchet clause). To be effective, the DSM system MUST be capable of reliably turning off the loads necessary to prevent the total base demand from exceeding a target level.

User inconvenience can be minimized, and acceptance improved, if relatively small groups have equipment turned off for short time periods. The load control rotates through all the groups instead of turning some off for extended time periods. For example, a 10% reduction in demand can be obtained by turning off the equipment in only 1 of 10 groups for the first 6 minutes of an hour. The next group is turned off during the second 6-minute period, and so on. Each unit is off only

6 minutes per hour, but the net effect is a continuous 10% demand reduction. A larger demand reduction will require that multiple groups be turned off during each 6-minute period.

For user acceptance of air-conditioner load control, the compressors and condenser (outside) fan will be turned off. The inside circulation fan will not be connected to the load controller. Continuous operation of the inside fan will make it less obvious that the compressor was turned off and will provide some additional occupant comfort when the inside air temperature rises above the thermostat set point. Water heaters at Fort Irwin are not included in the load control because most are gas-fired.

The demand and consumption savings potential for the DSM system at Fort Irwin was evaluated at the expected new rate structure, effective 1995, which will have a summer peak demand charge of $18.90/kW. The assumptions regarding installed equipment capacity that can be turned off, the demand profiles, and the conditions for load control are discussed in the following sections.

Air-Conditioner Installed Capacity

By 1995, approximately 2,145 air conditioners will have been installed in 991 residential housing buildings at Fort Irwin. The electric demand for an average air conditioner was estimated at 3.78 kW. Although the air conditioners were supplied by several manufacturers, all the units are similar in size. The average demand for the compressor and outside fan were estimated at 3.60 kW. The 0.18-kW demand for the inside air-handing unit fan will not be controlled and was not used as part of the savings estimates. For residential housing, the total installed capacity of air-conditioner compressors and outside fans is 7,722 kW.

The initial application of load control in nonresidential buildings will be limited to modular office buildings. These manufactured buildings consist of two to eight 12-foot-wide sections, each with an independent HVAC system, assembled into a single office building. Fort Irwin currently has 77 modular office buildings with 486 air-conditioner units, with new offices continuing to appear. The individual air conditioners installed on the office modules are similar to residential air conditioners in size. For modular office buildings, the total installed capacity of air-conditioner compressors and outside fans is 1,750 kW.

Future load control will be expanded to air conditioners on other buildings and to the central chillers, which service a variety of buildings in the cantonment area. Minimal AMR/DSM equipment will be required to control these large loads, but they will require some special procedures. Expanding load control to include turning off air conditioners in office buildings during off-hours and external lights when appropriate (such as the baseball field lighting) will provide additional energy conservation that is not included in this estimate.

Electric Demand and DSM Model

The demand and consumption savings are based on the difference between a typical electric demand profile and an electric demand profile modified according to a specified load control algorithm, and the electric rate structure. A computer program was developed by PNL to automate the calculations required to determine the demand and consumption savings. The program calculated hourly load control and electric rates for a full year to account for the demand ratchet clause.

The air-conditioner electric demand profile was assumed to be a linear function of outside air dry-bulb temperature. Fort Irwin in located in a desert climate, where moisture removal is not a major driver in air-conditioner operation. The electric demand was set to 0.0 below 70°F and 100% at or above 112°F. This means that no air conditioning is required below 70°F and the cooling equipment is sized for 112°F maximum design conditions. The outside air temperature is based on Typical Meteorological Year weather data for China Lake, California.

The program used the outside air temperature as a surrogate for total base electric demand. Reduction in peak electric demand is the goal of an actual DSM algorithm. The program calculates the maximum monthly demand and accumulates the total energy consumption within each electric rate period (e.g., summer and winter peak, mid-peak, off-peak) for a target outside air temperature.

This is equivalent to allowing the interior temperature to increase an amount equal to the difference between the actual outside air temperature and the target outside air temperature. For example, with a thermostat set point of 78°F, a target temperature of 100°F, and actual outside air temperature of 108°F, the DSM algorithm will turn off all the demand above that required to normally cool the buildings at 100°F outside air temperature. Therefore, the interior air temperature will increase to 86°F, and the demand will remain at the level it would have been at 100°F outside air temperature.

Estimated DSM Energy and Cost Savings

At a 100°F target outside air temperature, the estimated savings at the 1995 electric rate is $172K demand, $38K consumption, or $210K total per year. This requires turning off some air-conditioner load during 398 hours spread over 65 days of the summer. Additional DSM activities, such as off-hours control of air conditioners and lights and thermostat set back, will provide additional cost savings.

ECONOMIC ANALYSIS

The installation cost must be less than the savings generated from application of the proposed AMR/DSM system to be an economically feasible project. The following is PNL's preliminary cost estimate based on available information regarding equipment costs, installation costs, and numbers and locations of meters and load controllers at Fort Irwin. The final equipment specifications, system design, and cost estimate will be developed by the AMR/DSM system contractor.

The number and locations of meters and load controllers was determined by an on-site walk-through evaluation of buildings with Fort Irwin personnel. Costs are divided into field equipment (meter reading and load control), equipment labor, and central station and design.

Equipment Costs

Elimination of contract services required for monthly manual meter readings will require that the AMR system automate 124 electric, 105 gas, and 17 water meters. An additional 143 electric meters (a 10% sample of all family housing buildings) are needed to characterize residential housing energy usage, separated by building construction practices used during different eras. Still another 40 electric meters will be installed at electric substations, distribution points, well water pumps, and other miscellaneous buildings.

Most electric metering sites require only monthly readings of total consumption, which can be accomplished with relatively simple $150 meters. Critical monitoring sites, such as electric substation feeders and well water pumps, require full-function electric meters, which cost $500 each. These meters provide additional electric diagnostic measurements, such as kilowatt, kilowatt-hour, voltage, amperage, reactive power, and power factor for three-phase loads by phase and total. Most of the initial electric metering sites have existing meters and sockets. Later expansion to sites without existing sockets will significantly increase the installed cost per meter.

Most residential or industrial building gas meters can be retrofitted with an electronic head for $75 each. However, most of the distribution level gas meters are located without access to electric power. These sites will require installation of long wiring runs or stand-alone solar-powered systems, which will cost $3,500 each.

Most water meters can be inexpensively retrofitted with electronic heads but will require installation of long wiring runs to provide power and communications. The estimated cost is $500 per meter.

The primary focus of load control at Fort Irwin is residential housing composed of 781 separate buildings containing 1,735 individual housing units (each with an individual air-conditioning unit). Load control of commercial air-conditioning units is limited to 77 modular office buildings, containing 486 individual air-conditioning units.

Load control units that provide four relays each cost $250. Multiple air conditioners that share a building, such as duplex, triplex, or fourplex family housing and modular offices, will share load controllers to minimize costs. A charge of $75 per air conditioner is included to cover components required to adapt the low-voltage thermostat control wire as the primary means of controlling the outside unit of the air conditioner.

The communications infrastructure for all AMR/DSM devices requires a total of 350 packet radios at $450 each. They have to be installed on the secondary of every transformer that feeds the buildings with meters or load controllers. Packet radios will have to communicate with 100% of family housing because load controllers will be installed on all air conditioners. Four buildings are typically fed from each transformer. Future meters can therefore be installed with no additional packet radios.

Unlike residential housing, many of the commercial or industrial buildings are fed from individual transformers. However, multiple load controllers on modular office buildings can communicate with a single radio. Most of the utility meters are located at buildings or sites separated from the air-conditioner load controllers.

Equipment Installation Costs

The cost to install the equipment is estimated at 50% of equipment cost. Although this is a new service for SCE, its crews are expected to conduct an efficient installation of radios and electric meters. This assumption is supported by recent experience with a mass installation of 30,000 radios for an SCE distribution automation project. The number of gas and water meters to be automated is small compared to electric meters, but these will use a disproportionately large amount of labor because they are new, nonstandard connections that require power and power line carrier communications wire installation. The estimated cost for meter reading and load control equipment and field installation is $1.0M.

Central Station and System Design Costs
Fort Irwin staff will operate the ARM/DSM system from one central computer station. The central station will include a communications tower with two to four front-end radios and a UNIX host computer running control and application software with a user-friendly graphic interface. The central communications station, application software development, design, and project management will cost an additional $0.7M.

Cost Savings Resulting from AMR/DSM Activities
An itemized list of cost savings associated with AMR/DSM system activities is listed in Table 2. Air-conditioner load control provides 60% of the total $350K/yr savings. The "other energy conservation" item captures the ability to target projects toward buildings with high energy use, simplify conservation project justification, quickly locate power outages, diagnose power quality problems, and identify water leaks. Some other benefits, such as energy savings from self-directed conservation motivated by direct utility billing, turning off lights and air-conditioning equipment during off-hours, and accurate billing (resulting in fewer complaints from reimbursable customers, fewer meter re-reads, and reducing the utility clerk's work load), are not included.

Cost Summary
The total AMR/DSM system cost is estimated to be $1.7M. With SCE providing a turnkey AMR/DSM system, Fort Irwin does not have to provide any up-front capital funding but will be responsible for an annual service charge of $340K/yr (based on a 1.7%/month service charge). Fort Irwin will incur no additional costs because SCE is responsible for all system maintenance.

This charge is offset by the $350K/yr cost savings resulting from the initial AMR/DSM activities. Future expansion of the AMR/DSM activities is expected to result in additional savings.

Table 2. Cost savings from AMR/DSM activities

AMR/DSM Activity	Annual Savings, $K
Manual meter reader service	40
A/C load control - Consumption	38
- Demand	172
Fuel lead detection alarm	50
Other energy conservation	50
Total	350

CONCLUSIONS
Automatic meter reading technologies that do not have the capability for demand-side management load control need not apply. Whereas commercial utilities have thousands of meters over which to amortize the fixed cost of central station and communications infrastructure, federal sites have relatively few meters. The result is a relatively high cost per meter. AMR systems with two-way communications can provide DSM load control with self-diagnostics, a valuable feature unavailable with traditional load control systems having only one-way communications. However, by itself, load control is not cost-effective. Nevertheless, a combination meter reading and load control (AMR/DSM) system can be cost-effective.

Fort Irwin is planning to purchase a AMR/DSM service that will provide the metering and load control necessary to develop a system where the DPW provides utilities and utility services to all its customers on a cost-reimbursable basis. This, the first such system at a federal site, will be a model for others to followed.

ACKNOWLEDGMENTS
The Pacific Northwest Laboratory is operated by Battelle Memorial Institute for DOE under Contract DE-AC06-76RLO 1830.

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