LOAD MANAGEMENT

Electric power is one major industry that has shaped and contributed to the progress and technical advances of humankind over the past century. Power must be available to the consumer in any amount upon demand. Modern industry is almost entirely dependent on electric power for its operation. Lifestyles in our society are changing constantly. We have replaced oil lamps with electric lighting, and wood burning stoves with electric stoves. If the natural air is not at the desired temperature, we have systems to change the temperature to a comfortable level whether it be by heating or cooling the air. Our shower water can be regulated to the exact temperature. Dirty dishes and clothing are now washed by electric machines. We are entertained by televisions, videocassette players, and sound systems.

All of the aforementioned systems have one basic characteristic in common: They require electricity to perform the expected functions. In generating the power, the concept so far has been straightforward. If the society demanded more power, the power companies would simply find a way to supply users even by building more generation facilities. This concept of doing business has been labeled as supply-side management (see Ref. 1 for further explanation). Basically, if the consumer was willing to pay for the power, the companies would provide it. The point is that comfort and aesthetics were the major concerns since energy was inexpensive and people were ignorant of the consequences of a wasteful attitude toward energy consumption. Supply-side management techniques worked well from the inception of power generation until the early 1970s; the 1970s, however, ushered in some new attitudes and concerns.

In the early 1970s, economical, political, social, technological, and resource supply factors have combined to change the utility industry's operating environment and its outlook for the future. Inflation, which seemed to be out of control, affected the prices of all consumable items and products, including power. Humankind began to realize the damage to the atmosphere and ecosystem from the gluttonous consumption of fossil fuels. According to the American Council for Energy-efficient Economy, "Electric utilities are responsible for approximately 65 percent of the sulfuric dioxide emissions in the United States (2)." Nuclear power generating plants were utilized in the 1970s but were heavily criticized because of fears concerning the safe disposal of radioactive waste. The future outlook of power companies was very uncertain. Power companies began to look for other viable solutions to their problems and began to develop load management techniques to control demand and energy electrical consumption, as described in Ref. 2.

Load literally means the amount of electric current drawn from electric circuits. Load can be better explained as the amount of electric power that is drawn from a power line, generator, or other power sources. Load management, sometimes referred to as demand or energy management, can be considered as controlling the amount of electric power used. The demand charge is usually applied to commercial, industrial, and bulk residential customers on the basis of sustained maximum kilowatt (kW) or kilovolt-ampere (kVA) demand (for at least for 15, 30, or 60 min) for the billing period. This charge is representative of the capacity that the utility must install. The energy charge is the direct usage of electricity measured in kilowatt-hours (kWh).

Load management is a method to alter or reshape the electric utility load as a function of time. The purpose of load management is to reduce peak demands to level the daily or annual electric demand. A typical weekly load curve for a power system is shown in Fig. 1. The definition of load management given by the US Department of Energy is as follows (3):

> Load management is a system concept of altering the real or apparent pattern of electricity in order to (1) improve system efficiency, (2) shift fuel dependency from limited to more abundant energy resources, (3) reduce reserve requirements, and (4) improve reliability to essential loads.

An important point of this definition is that load management is a system concept. The entire utility system, including generation, transmission, and distribution, is affected. Load management is the action initiated by the utility or one or more of its customers to control load growth, alter the shape of the load curve, or increase supply through nonutility or nontraditional sources. The end result could reduce capital expenditures, improve capacity limitations, provide for economic dispatch, reduce the cost of the service, improve load factor, or improve system reliability.

The concept of load management has been further divided into use management and supply management according to the location at which the use is taken. The use-management alternatives apply to the load side of the meter in which the customer responds to an incentive offered by the utility. The use-management alternatives include direct and indirect control of customer loads, and customer energy storage. Direct control of customer loads has been implemented by utilities in the cycling of air conditioners, water heaters, and other appliances. Indirect control of loads has undergone experimentation and has been implemented by various forms of electricity pricing and rate structures to encourage customers to change usage patterns. The supply-management alternatives involve the use of concepts such as central station storage and expanded interconnections to affect the bulk supply. Emergency customer energy storage technology offers the potential of altering electric usage patterns by allowing customers to save energy for use at a later time.

The topic of load management analyzes the various aspects of demand-side management, supply-side management, energy management systems, power shortage management, energy audits, environmental issues, power fluctuations, transmission losses, electricity pricing, and other related problems in detail. The techniques discussed in this article can reduce the damage to our atmosphere and ecosystem, control inflation, and restrict the consumption of fossil fuels. These technologies are not the only ones that are useful, but they seem to be the ones most often considered and discussed.

DEMAND-SIDE MANAGEMENT

The selling of power is different from the selling of other items because power cannot be stored. Power has to be generated at the time it is needed or demanded by the consumer. Power curves or load curves are used to help power companies to determine power demands at certain times of day. These

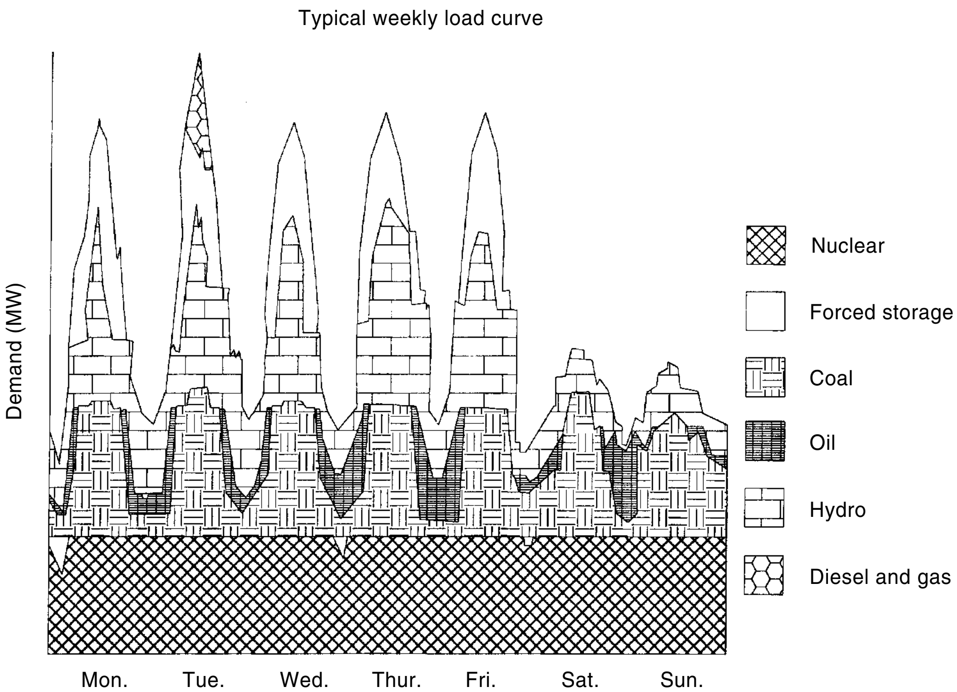

Figure 1. Typical weekly load curve.

power curves are accurate, but there exists a certain margin of error, which is referred to as the margin of operation. Power companies strive to keep this margin as low as possible because this energy produced is never utilized.

Power Curves

Demand-side management describes the planning and implementation of activities designed to influence customers in such a way that the load shape curve of the utility company can be modified to produce power in an optimal way. There are six demand-side management load shapes, each shape representing its own objectives: peak clipping, valley filling, load shifting, strategic conservation, strategic load growth, and flexible load shape. The demand-side management curves are shown in Fig. 2.

Direct load control and interruptible rates are used to reduce demand during peak load hours to clip the peak. This peak-clipping effect can lower the utility's cost of service by reducing the need to operate at its most expensive unit and by postponing the needs for future capacity additions. The valley-filling technique encourages customers to use more energy at times when the utility company is most likely to have low-cost energy available; this practice can lower the cost of service by spreading fixed capacity costs over a longer base of energy sales and reducing average fuel costs. Load shifting encourages customers to move their energy consumption from peak to off-peak times, thus producing the combined effect of peak clipping and valley filling. In strategic conservation, utilities adopt focused programs to encourage efficient energy use to reduce demand not only during peak hours, but also at other hours of the day; this can reduce average fuel cost and can postpone the need for future utility capacity addition. In strategic load growth, utilities encourage customers to adopt electrotechnologies, either to replace inefficient fossil-fuel equipment or to improve customer productivity and quality of life; this reduces the average cost of service by spreading fixed cost over a larger base of energy sales, and thus benefits all customers. In the flexible load shape, programs such as demand subscription service and priority service pricing are used to tailor reliability of service to individual customer needs. Utilities can realize both operating and future fixed costs by allowing dispatchers flexibility to reduce or postpone demand for selected customers (interested readers can refer to Ref. 4).

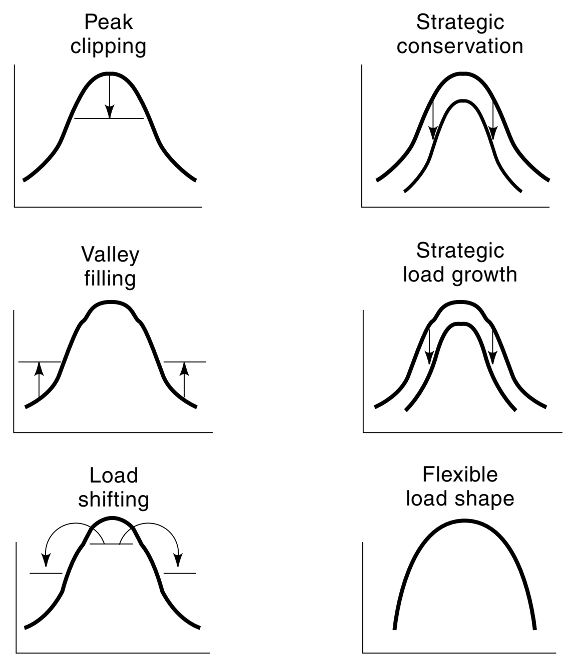

Figure 2. Demand-side management load shape curves (Demand in megawatts versus time).

Lighting Loads

The subject of lighting is of interest to everyone. Residential lighting consumes approximately 30% of all energy used in the home. Many people are not aware that a compact fluorescent light bulb exists, let alone that this light bulb lasts longer and uses one quarter of the energy of an incandescent bulb. A 60 W incandescent bulb lasts about 750 h; a fluorescent bulb with one third the wattage will generate the same light and burn for 7500 h to 10,000 h in five to ten years of use. If an area demands the use of incandescent bulbs, it is helpful to know that a single 100 W bulb illuminates as much as two 60 W bulbs. New technology is developing the electrode-less fluorescent or E lamp. This lamp uses radio waves to ionize an argon gas in the fluorescent tube. The ionized gas then generates light by standard fluorescence methods. The 85 W E lamp, manufactured in Europe, is estimated to last 60,000 h. Day lighting consists of using your windows and sky lights as much as possible to provide light and save money. The consumer must be aware of what type of lighting is needed and purchase energy-efficient bulbs (for more information see Ref. 5).

Motors

A Department of Energy (DOE) report (discussed in Ref. 6) estimates that over 50% of all electric use in the United States is for electric motors. Motors over 75 kW are, at present, very efficient and motors under 1 kW are difficult to improve. Efficiency improvements for motors are essentially needed in the 1 kW to 75 kW range. The following improvements can be made easily:

1. Core losses, which account for 25% of total losses, are reduced by using a high-grade silicon steel in the rotor and stator windings.
2. I^2R (I is current, R is resistance) power losses in the rotor and stator windings will amount to 60%. These are reduced by using copper windings instead of aluminum or by increasing the conductor's cross-sectional area.
3. Friction in bearings and windage of cooling fans will add another 5%. Better bearings will reduce friction, and fans have been redesigned to minimize losses.

With these modifications, a 12 kW energy-efficient motor can increase its speed from 1747 rpm to 1766 rpm (revolutions per minute). This speed increase can reduce the power consumption by 3.3%. Adjustable-speed devices have increasing applications in process and are well suited for heating, ventilation, and air conditioning (HVAC) use because they offer excellent motor control and energy reduction. The selection of energy-efficient motors is discussed in Appendix A.

Heat Pump

The purpose of HVAC systems is to control the air in our homes to make them as comfortable as possible. The heat pump transfers heat from the outside air into a house in the winter and vice versa in the summer. A reversing valve for the refrigerant flow allows the same heat exchanger to serve two purposes: One coil operates both as a heating evaporator and cooling condenser, and the second serves both as a cooling evaporator and heating condenser. In the normal operation of a heat pump, some of the heat for the heat pump's thermodynamic cycle comes from the outdoor air rather than from resistance or combustion heaters; thus overall heat pump efficiency can be quite high, and energy savings over alternative heating methods can be substantial. Supplemental heating capability is almost always necessary, especially in areas where the winter temperatures fall to 0° to 5°C.

Instead of ambient air, some heat pump systems use water as the heat source and sink. One example of these systems is the "ground water source heat pump" (5). The groundwater source heat pump uses groundwater to transfer heat from a dwelling to the groundwater in the summer and transfers heat from the groundwater into the dwelling in the winter. The groundwater source heat pump is shown in Fig. 3.

Home Automation System

Smart home products can be utilized to control the inner working of a home (7). A communications bus can be interfaced with the in-home entertainment system, HVAC subsystems, lighting system, communication subsystem, personal computer subsystem, or any other desired system. Programmable demand controllers are electromechanical or microprocessor-based devices that automatically limit demand by temporarily switching off scheduled loads. Loads may be spread out in a sequence predetermined by the customer, or interruptions may be rotated among several loads. The block diagram for this system is shown in Fig. 4. Benefits to the customer are a function of site-specific load reduction and the rate structure in place, but one utility review reports demand reductions of 1 kW to 5 kW per house in the summer and 1 kW to 2 kW per house in the winter. In the southern region of the United States, it is estimated that 34% of energy consumed is for space heating and cooling. It is easily deduced how programmable controllers can have an enormous impact on the savings on our utility bills.

Applications of Demand-Side Management

When we look at the technologies involved in the implementation of demand-side management ideology, we realize that not

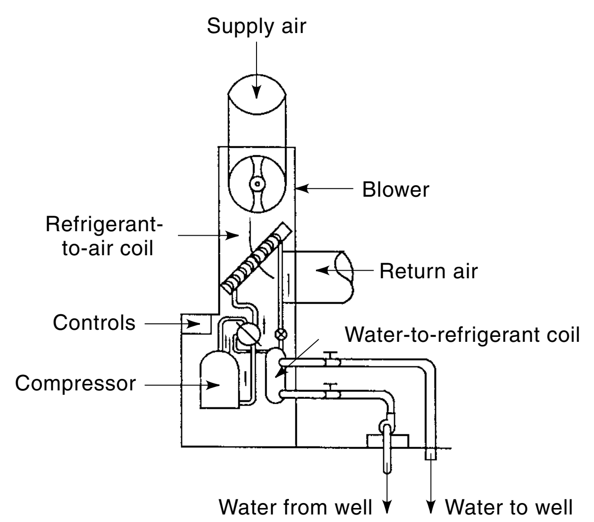

Figure 3. Groundwater source heat pump.

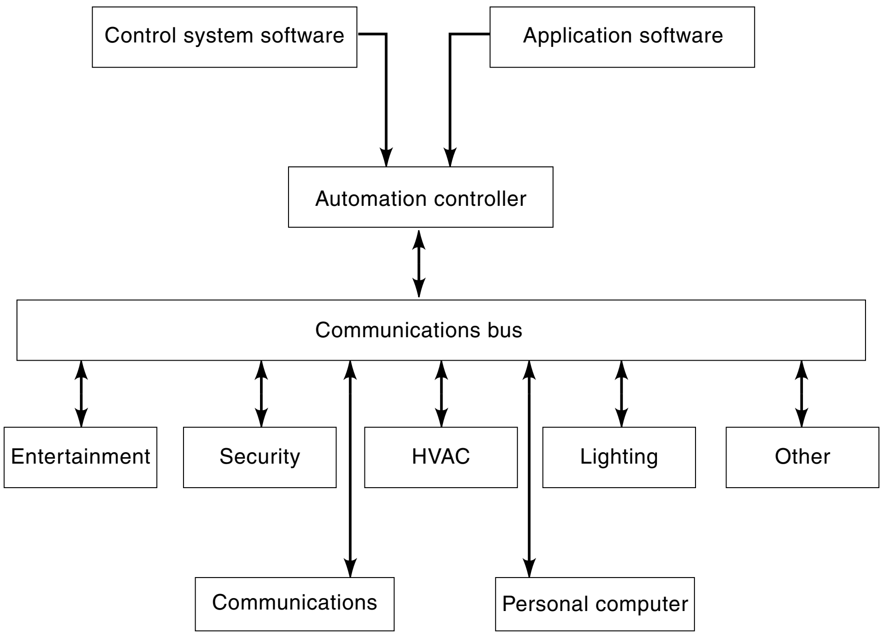

Figure 4. Integrated home automation system structure.

every system will prove to be beneficial for every home. The power company must devise some incentive to motivate consumers to implement the desired system in question. In a nutshell, demand-side management is a give-and-take process. The power companies will make sacrifices (either rate reductions or interest-free financing for specific technologies related to load shape objectives) and consumers will make sacrifices by exploring the options available and altering their lifestyles moderately. The bottom line is that less energy is wasted. This attitude or discipline has attained the label of demand-side management.

SUPPLY-SIDE MANAGEMENT

Electric energy is mostly produced from commercial energy sources like coal, petroleum oils, natural gas, hydro power and nuclear power. Hydro power is the only renewable commercial energy source. Nuclear energy is receiving heavy criticism from the public. The noncommercial energy sources are receiving more attention in most countries due to the depletion of commercial energy sources, which creates ecological and environmental problems.

Supply-side management is basically concerned with those systems and activities that lower the power demanded by customers and consequently decrease the demand placed on the power-generating facility. Power companies also benefit from supply-side management in that the need for new generation systems or plants will be curtailed or even eliminated by this decrease in power demand. The types of supply-side demand technology that will be discussed here are as follows:

- Waste-to-energy generation
- Superconductivity
- Wind generation
- Solar energy
- Pumped hydro
- Compressed air energy storage
- Thermal storage

Waste-to-Energy Generation System

A new and exciting area of power generation, which is just developing and is showing a very promising future, is the waste-to-energy generation (8) system. In Palm Beach, Florida, waste-to-energy power generation will be beneficial in taking care of two major problems simultaneously. One problem is the danger of damage to precious groundwater and the other is the high cost of building new power generation facilities. A power company is using third-generation combustion technology with two boilers that power a 14-stage turbine. A system, called a “Recoverator,” is designed to recover energy in the form of high-grade steam from 3000 tons to 3100 tons of solid waste per day. The unit also recovers the steel wire from steel belted radial tires. Steam production ranges from 900 kg to 1000 kg of high-grade steam per hour while disposing of 120 kg to 1200 kg of rubber per hour. This process takes place within a space of only 65 m^2. A new facility for waste-to-energy generation in Oklahoma generates up to 109,000 kg of steam per hour to generate 16.5 MW of electricity for sale to the local public utility company. The city has received $10.4 million in revenue since 1986. Waste-to-energy power generation is not the whole answer, but a very practical part of the system, as technology is utilized in improving our standard of living.

Superconductivity

Researchers and scientists have discovered that certain substances, when cooled to near absolute zero, will conduct electricity with no resistance. Approximately 7% of the electricity produced by conventional generation is lost due to resistance, before it reaches the customer. To attain the maximum benefits of a superconductive system, we must utilize superconductive transmission with superconductor generating systems and superconductive storage devices simultaneously. Since the line resistance would be negligible, the power loss would be almost nonexistent, thereby making the proposition of transcontinental power transfer a very real and possible option. The energy generated at hydropower generation sites in the wilderness of the United States could be transferred to virtually anywhere.

The Council on Superconductivity for American Competitiveness (9) wants to "see an entire electricity system based on resistance free technology from the power source to the motors and switches that eventually use the power." The initial cost of this system is estimated as follows: $60 million to produce a 20 MW prototype generator; $50 million for a 100 m long 500 MV transmission line; $30 million for a 4 kV/138 kV transformer; and $55 million for a 3700 kW electric motor. The cost will tally several million dollars to develop this system, but the rewards would overwhelm the expenditures.

Superconducting Magnetic Energy Storage. Electricity (direct current, dc) can be stored in magnetic fields wherein the energy stored is proportional to the inductance times the square of the current (10). An energy storage system based on magnetics would involve an ac-dc-ac converter system (batteries) and large coils of superconductivity material. To achieve superconductivity, the conductor is maintained in a bath of liquid helium at about 1.8 K. Since there are no moving parts in the coil and electrical resistance is zero, the efficiencies can exceed 90%. The cost per unit of stored energy decreases by 21% for each doubling of storage capacity. The United States Department of Energy has already built a small storage unit that has proved to be very successful in damping low-frequency oscillations. The capability of this system to store energy could prove to be a major breakthrough because power companies could generate power and store it to meet peak load demands. Huge amounts of energy in superconducting magnetic energy storage (SMES) is technically feasible, and its ability to deliver extremely high bursts of power makes it very attractive.

Wind Power

The United States is the leader in the development of wind power technology, but Japan, India, and many European countries, including Denmark, are making significant progress. In the United States, California is the leader at the moment. The research in wind power is more concentrated in California because California has adopted and implemented some of the strictest clean air statutes in the United States, and possibly the world. The cost of energy in the west and northwest is approximately $0.09 per kilowatt-hour. The goal of the wind energy industry is to develop wind generators that will be competitive with this rate. As mentioned in Ref. 11, the US Wind Power Commission announced a joint venture in which it intends to build a new 33 m wind turbine that would be more advanced and efficient to generate 800,000 kWh per year with a wind speed of approximately 10 m/s. Minnesota's Department of Public Services has operated three bonus 65 kW turbines on the Holland site. When operating only 56% of the time, the turbines generated 270 MWh of usable electric power.

Solar Energy

Heating water for residential use accounts for approximately 31% of the power used in US residential dwellings. Solar water heating has been one of the most successful thermal applications of solar energy use. Solar water heating has already been proven reliable and viable in areas such as preheating water for industrial uses and providing hot water for hospitals and hotels. Even after this commercial success, domestic solar water heaters have not yet proven to be successful in residential use. Many believe that the reason for this peculiar dilemma is that many users do not fully understand the necessity of accurate monitoring and proper maintenance of a thermosiphon solar system. If these systems are not monitored correctly, they will not achieve the proper level of efficiency.

A continuous flow type of solar water heater (12) can overcome these problems associated with residential use. Almost all domestic solar water heaters have operated on the thermosiphon effect and have been installed on the roofs of homes. This has led to many problems. The continuous flow domestic solar water heater operates with a performance comparable to that of the thermosiphon type with no operational problems. Only the collector is on the roof, and the storage tank is in a convenient place in the building. The collector and the tank are connected through a small-diameter, insulated pipeline. Auxiliary electric heating can be operated manually if needed. A continuous flow type water heater is shown in Fig. 5.

Pumped Hydro

The use of pumped hydro facilities to meet peaking capacity has been growing at an increasing rate for over about 50 years. In addition, pumped hydro facilities can contribute one or more of the following functions to the electrical power systems: (1) load regulation, (2) quick response capacity to offset short-term generation or transmission outages, and (3) increase in overall system energy. In addition, pumped hydro is also useful with water supply projects, flood control, and nuclear cooling facilities. Electricity is used to operate a motor-pump combination to pump water to an elevated reservoir. When energy is required, water is allowed to flow down to a lower reservoir through a turbine generator combination, much like the turbine generators in conventional hydroelectric plants. The energy stored is proportional to the head (height differential between upper and lower reservoirs) times the stored volume of the water. In areas where topographic or ecological considerations rule out pumped hydro, underground pumped hydro (UPH) would have its lower reservoir

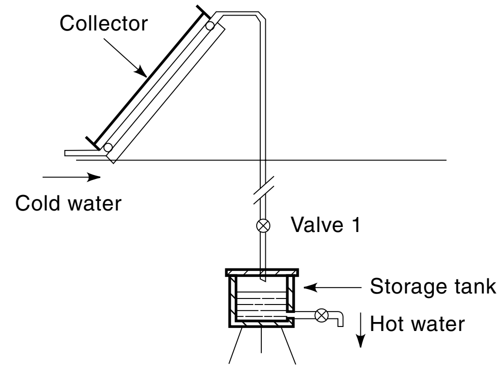

Figure 5. Solar water heater.

located about 2 km below the earth's surface in a competent hard rock cavern (13).

Both pumped hydro and UPH, like conventional hydro, have very fast response characteristics (emergency full power capability in 10 s) and very high efficiencies (72% to 75%). These factors, along with low capital costs, have led to the construction and operation of 18,000 MW of pumped hydro in the United States. Pumped storage will typically be the alternative choice for electric utilities having favorable topography.

Static Frequency Converters. Pumped hydro motor-generator units are traditionally used as synchronous condensers to provide reactive power for voltage support and regulation. However, they can also be used to provide rapid load response to support system load requirements. To accomplish this, the machines must be capable of quick transition from synchronous condenser to generator operation. There is a problem of transient reverse power flow that can impact system frequency during this transition. The duration of reverse power flow can be as long as 60 s with a maximum magnitude reaching 60 MW. This problem is not considered serious on a large interconnected bulk power system, however, on an isolated system, the pumped hydro unit MVA is a significant proportion of the system capacity, and the transient can produce serious consequences. The effect of reverse power flow will result in voltage and frequency dips. Voltage will be corrected within milliseconds using voltage regulators. A serious consequence is the impact of a frequency transient on the operation of base load nuclear or thermal units, and the possibility of a forced outage unit trip.

Utilizing a static frequency converter (SFC) as an asynchronous link between the generator and the power system eliminates the negative impact of reverse power flow. In addition, the SFC will feed instantaneous short-term power into a weak power system within milliseconds by providing an electrical asynchronous link between the rotating masses of the turbine/generator set and power system (14).

Compressed Air Energy Storage

The compressed air energy storage (CAES) plant is a more cost-effective option for peaking power needs and uses less natural gas or other petroleum fuels (15). CAES involves the compression of air into an underground cavern or reservoir (excavated rock, solution mined salt, or aquifer), where it is stored. Favorable geologies exist in about 75% of the United States. During generation, the air is expanded through a turbine to drive the generator. Economics dictate that heat be added to the air from a thermal store or through combustion of a fuel prior to the expansion-generator-phase. Incidentally, a higher plant load factor of operation is ensured for the thermal station of the grid as off-peak power is utilized for storing compressed air in underground caverns. The grid operation will also be stabilized, narrowing likely voltage and frequency variations. The operating concept of a CAES scheme for peaking power is detailed in Fig. 6.

Installation and Operation. A CAES plant rated at 290 MW using two underground salt caverns has operated since 1978 in Huntorf, West Germany. The second plant in the world, but the first in the United States, is rated for 110 MW and has been operating since June 1991 at McIntosh, Alabama for the Alabama Electric Cooperative (AEC) power system. The load demand curves indicate that the CAES plant of 110 MW is extremely useful for managing day peaks, and the system could use another similar plant. (The Electric Power Research Institute [EPRI] helps utilities in planning, design, cost/benefit analysis, procurement, and performance monitoring). The third plant is being built by an Italian utility using an aquifer store. The 25 MW plant is located in the Larderello area near Sesta, Italy (13).

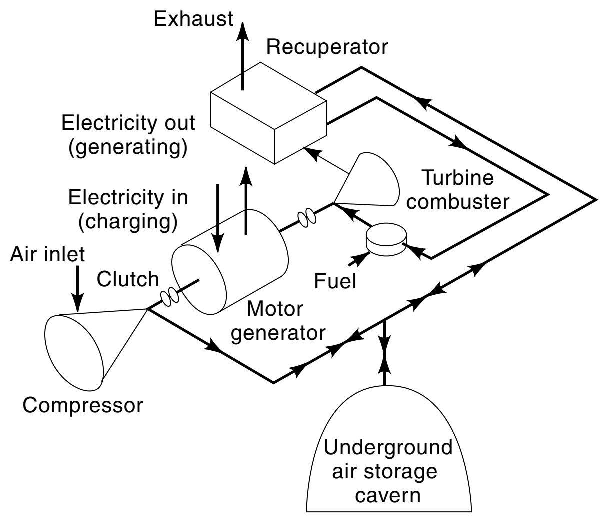

Figure 6. Concept of compressed air energy storage scheme.

The CAES method offers an effective alternative method for meeting peaking power needs efficiently and economically. This method uses only about one third of the petroleum fuel as compared to a conventional open-cycle gas turbine used for peaking purposes. Air pollution is also reduced by nearly one third.

Thermal Storage

Thermal storage (16) is comprised of an electric furnace, with a fan, which draws hot air into a gravel storage medium during the night, when power is inexpensive. During the day, the fan operation is reversed and heat from the gravel enters the house. This new storage furnace is 40% cheaper than a comparable European design because it uses ordinary basalt gravel as the storage medium instead of expensive ceramic brick.

The same technology can air condition buildings in a warm climate by cooling water or making ice. A 7.5-million-liter cool-water storage tank was developed by the 72-story InterFirst Plaza in Dallas to save $150,000 a year in electric bills.

POWER SHORTAGE MANAGEMENT

Power shortages will arise when power demand exceeds availability. Power shortages can be in terms of peaking power needs (in kVA or kW) or energy requirements (in kWh) or both. Power shortages can create adverse conditions; for instance, the industrial production of goods decreases; agricultural cultivation will be lowered; domestic customers suffer inconveniences. In addition, the sale of goods and services are affected in retail commercial premises. Power shortages occur due to untimely planning of additional power capacity. These shortages require time and resources to correct and must be managed until adequate power is installed. In developed nations, power companies can afford to purchase from neighboring utilities. In developing countries, neighboring utilities also suffer shortages; this makes the power purchases impossible or difficult. Power cuts are imposed on identified large power users. The percentage cuts are based on peak power demand and energy consumption by the consumer. The quotas are set for the peak power demand and energy consumption from the normal usage of the previous year. When quotas are exceeded in any month, power supply is suspended for that month and the excess used would be adjusted in the next month's quota or penalties levied. State government empowers the utilities to enforce these power cuts (17).

The customers, suffering from frequent power cuts or supply interruptions caused by the utilities, set up captive generators to manage the situations. Since the cost of power from the utility companies is much cheaper than that of captive generators, the industries would consume the entire quota allotted by the utility. If financial losses or inconveniences to customers are considered, then costlier power is better than no power at all. Many customers suffering from power shortages prefer buying such costlier power from the owners of captive generators. The utilities assist such sales by wheeling power through their grid after imposing wheeling charges to compensate losses. The larger captive generators are run in synchronism with grid supply during peak hours and power shortage periods.

In India, most of the State Electricity Boards (SEBs) have difficulty meeting the lighting load between 6:00 and 9.30 P.M. Some SEBs have difficulty meeting early morning peak demand between 6:00 and 9:00 A.M. due to numerous lift irrigation loads during these hours. Most of them operate at a frequency lower than the standard value (50 Hz) during peak hours. This continuous dilemma of meeting energy demand creates planned and unplanned power outages. These outages are especially critical during the summer months because of low water levels in the hydro reservoirs. Hydro power sources can easily be utilized to meet the peak demand. If the power availability is reduced due to monsoon failure, the SEBs resort to unscientific load shedding on rural areas, in rotation, and operate the interconnected power grids down to 48 Hz for most cases (18).

Demand Conservation in Lift Irrigation Pumpsets

In several states of India, power consumption by lift irrigation pumpsets is between 25% and 40% of total consumption. About half of grid peak demand on dry days is contributed by these pumpsets. It is possible for these states to bring down grid peak by 15 to 25% by enforcing restriction in hours of supply to pumpsets. First, lift irrigation pumpsets are classified into two groups—namely, A and B. Each group is given a daily supply for 6 h either in the morning (6 A.M. to 12 noon) or in the afternoon (12 noon to 6 P.M.). Neither group is allowed to operate from 6 to 10 P.M., as these are the peak lighting hours. But all pumpsets can work from 10 P.M. to 6 A.M. next day, which are low load hours. The average number of hours of operation of most of the lift irrigation pumpsets is only 5 h to 6 h.

If the aforementioned scheme is implemented successfully, it will greatly enhance the capability utilization of entire power system equipments, save investments, reduce line losses considerably, and improve voltage regulation to rural areas. The greatest advantage to rural consumers is that they can get 24 h of lighting supply for domestic loads by this voluntary compliance scheme.

Energy Conservation in Lift Irrigation

The pumpsets are meant for drawing water from a water source (e.g., a well or a canal) and pumping it to the level of the farm. The losses in piping due to friction result in additional consumption of energy in the pump's engine. A case study (19) was performed in 1988–1989 to review the existing pump, piping, and foot valves. After modifying the design of these items in 100 pumpsets, it was noticed that there was a 63% savings in diesel consumption. Efforts must be made to educate farmers to operate pumpsets efficiently and conserve energy.

Demand Conservation of Industrial Loads

All continuous and three-shift industries will work 24 h. If the industry operates single shifts, they should be able to start at 9 A.M. and close by 6 P.M. before the commencement of the lighting load peak. If the industry operates on two shifts, it should be planned with one day shift with the timing of 9 A.M. to 6 P.M. and one night shift, from 9 P.M. to 6 A.M. the next day. These changes can reduce demand by at least 10%. The weekly holidays of all industrial and commercial establishments coming under the Factories Act have to be prenotified. They should be statutorily staggered over the entire week instead of all of them having mostly Sunday as a weekly holiday. Peak demand can be reduced by 5% due to this single measure.

ENERGY AUDIT MANAGEMENT

The most important step in reducing energy losses is to carry out a systematic and scientific energy audit of power systems and survey of different categories of load. This requires installation of high-accuracy data logging meters to record demand, active/reactive power, and the time of supply ON/OFF. Energy audit aims at saving power and reducing energy bills. The peak demand reduction would enable power companies to make power available to other users and to reduce the prevailing power demand.

Industry

The need for energy audits must be compelling to receive approval by industries' top executive management. Since electrical engineers in the power industry are committed to the operation and maintenance of equipment, the concern for increased production takes precedence over energy conservation. Hence it is better to request external energy auditors, who can make a general survey of all power uses and document all power flow in units, maximum demand in kilovolt-amperes, power cost, and average power factor for about a year. A cost/benefit check will be performed to enable listing priorities of implementation.

Recommended Energy Conservation Techniques. The following recommended energy conservation techniques can be adopted easily and all the expenses can be recovered within two to three years (20):

1. The energy bill can be brought down easily by improving power and load factors. Power factor improvement reduces peak demand. The power factor can be increased by installing shunt capacitors (switched type) in the appropriate locations. In special cases, series capacitors can also be used, where load fluctuations are considerable.
2. Electronic controllers (soft starters) are available to save power consumption in all motors that are used for fluctuating or low loads. These controllers maintain the operating efficiency and power factor nearer to the full load values and thereby save up to 30% of energy.
3. Existing motors can be replaced with higher-efficiency motors. Also, changing the existing transformers to on-load tap-changing transformers will improve the voltage conditions and thereby maximum demand.
4. High-efficiency miniature or compact fluorescent lamps with electronic ballasts consume 9 W to 25 W of power as against the standard 40 W. For indoor use, fluorescent tubes must be used in preference to filament lights. Electronic ballast takes the place of starter and chokes. The power saving is estimated to be around 30%. Electronic regulators for fans also save considerable energy.
5. Staggering the working hours of nonprocess auxiliary and service loads can reduce the peak demand by considerable amount.

Implementation of Energy Audits. Implementation of energy audits with the cooperation of the power industry will reveal several areas of conserving power and reducing power costs. Many power companies have encouraged energy audits and conservation by subsidizing partly or fully the energy audit expenses, provided the industries take serious efforts to implement the short-term feasible measures suggested by the energy auditors.

Residential

Every home is different in its need for energy efficiency. The energy efficiency of a home is greatly affected by the quality of its construction. Most power companies will evaluate the energy efficiency of a home, free of charge to a customer. The power company can calculate the benefits of replacing old, inefficient equipment, making energy-efficient structural changes, and using energy wisely. The payback period for each of the changes will help to determine a priority list of improvements. A free evaluation can be conducted by a certified professional who will inspect the following nine items in a home: (1) attic insulation, (2) wall insulation, (3) floor insulation, (4) storm or double-paned windows, (5) storm or insulated doors, (6) caulking/weather stripping for windows/doors, (7) heating and cooling equipment/heat pump, (8) advanced water heating device, and (9) ducts and pipe insulation.

By using a programmable thermostat, one can lower and raise the temperature automatically to match a time schedule. The stepdown thermostat is so convenient and efficient that it quickly pays for itself. The heat pump offers a cost-effective solution that is more than 300% efficient in heating and cooling performance. By following simple maintenance schedules, maximum efficiency can be obtained from the heating and cooling system. A heat pump water heater operates much like the heat pump and can reduce water heating costs while it cools and dehumidifies the area it surrounds. A solar water heater can also be used. Wrapping the water heater's tank with insulation helps maintain the temperature in the water tank by protecting it from the cooler surrounding air. In addition, modern, energy-efficient refrigerators can reimburse the customer for the extra money spent by minimizing energy usage.

The efficiency level of a home's construction, the efficiency rating of the equipment installed in the home, and the lifestyles of the people using energy in the home can help to maintain comfort without waste. A well-sealed and insulated house can cope with both hot and cold weather and requires less work from the heating and cooling system. A free audit inspection will reveal energy-wasting practices, and with the customer's cooperation, lower costs of energy can be utilized in the home. (For further information, call your local utility company or see Ref. 21.)

ENERGY MANAGEMENT SYSTEMS

Energy management systems (EMS) range from programmable thermostats and time clocks to multi-million-dollar, computer-based systems for managing the operating systems of multibuilding complexes. Some systems, particularly the large ones, also include building security and comfort controls; however, the basis of the EMS portion of the system is energy consumption reduction. EMSs are typically installed to reduce the operating costs of a facility by improving the operating efficiency. The objectives of EMSs can be briefly stated as follows (22): The start/stop and duty cycling control can reduce equipment operation to a minimum requirement or completely shut down appointed devices on time-of-day or occupancy schedules. Temperature setpoints decrease loads on equipment when the building reaches temperature stabilization by comparing inside and outside air temperature and humidity. Demand control, also known as demand limiting, is a technique that monitors the energy use of a facility and limits the peak demand by shutting down specified equipment on a priority basis. As a result, the customer will get reduced demand charges while simultaneously clipping the peak demand for utilities. The point monitoring/alarm status feature informs the operator/technician of system performance or failure.

Energy Management Systems for Commerical Buildings

EMSs offer a wide range of control strategies designed to provide heating, cooling, ventilation, lighting, and hot water, as well as special processes required by the building. The various types of energy consumption in commercial buildings are as follows:

- HVAC—44%
- Lighting—41%
- Refrigeration—15%

EMSs can reduce energy waste by automatically controlling energy use. EMSs can be characterized by their components, the methods of information transmission, the functions performed, and the control logic employed. There are six basic components that are used in EMSs: sensors, actuators, field panels, modems, communication links, and controllers or processors. A typical EMS controller is shown in Fig. 7 (22).

Energy Management System Benefits. A school district in Pennsylvania employed a control system company to install an EMS in four buildings that were comprised of a high school, two elementary schools, and an administrative/kindergarten facility. As a result, the district reduced electrical usage by 450,000 kWh and natural gas consumption by 270 Mm^3 annually. Furthermore, the EMS reduced total energy costs by $100,000 per year, with a projected savings in excess of one million dollars over 10 years. Thus, the EMS is a proven and viable technology to reduce energy consumption.

Energy Management Systems for Residential Dwellings

The U.S. electric industry is constantly confronted with new challenges. Increases in system peak; rising plant construction costs; rigid environmental, regulator, and custom group standards; and the ability to meet customer satisfaction are the primary areas of concern.

There are several Interactive Energy Management Systems (IEMSs) available to residential customers that conveniently and automatically control HVAC systems, electric water heaters, and other small appliances in response to changing price signals that reflect the utility's varying cost of producing and providing electricity. These IEMSs let residential customers balance comfort with economy. The system monitors electric usage and costs to date and estimates monthly electricity bills in advance. The utility can also exercise load control with remote meter reading. Customers can choose to buy more expensive energy or to defer usage to times when energy is less expensive. This helps maximize the value of electric energy purchases and provide better understanding of energy consumption.

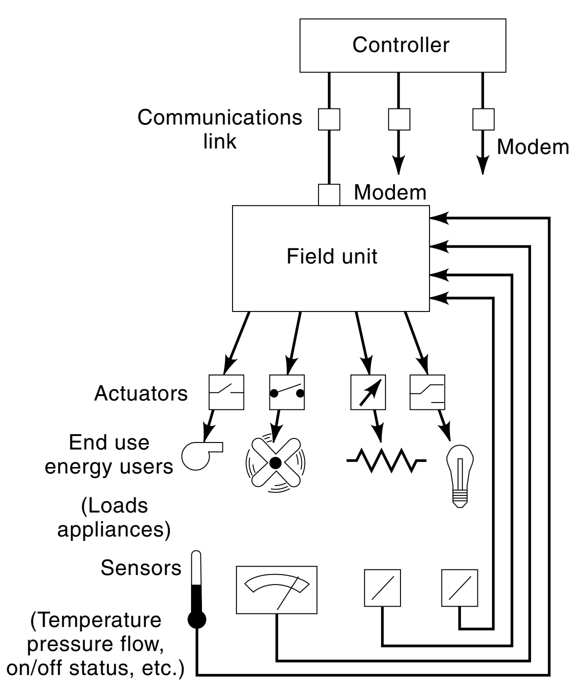

Figure 7. Components of typical energy management system.

IEMS Operation. IEMS components include (1) programmable thermostat, (2) controller, (3) major relay, (4) modem, (5) system manager, and (6) electric meter with memory. The utility company electronically sends the customer the variable electric rate with four or more price levels in one-hour increments such as 2¢/kWh (low), 6¢/kWh (medium), 12¢/kWh (high), and 18¢/kWh (critical). The pricing is stored in the electronic memory of the electric meter. The customer can program the HVAC settings to the desired comfort level, or temperature, for each of the possible prices with the controller. The controller ensures that the water is heated in the lower-price periods and that water is available at the time of need. The controller can control other appliances—lamps, a coffee maker, a dishwasher, washing machine, outdoor lights, etc.—according to the programmed instruction. The system manager, a computer located at the utility, supports the interactive communications. The system is easy to install, and its presence does not change, disrupt, or intrude on a home's interior design (23).

IEMS Benefits. The IEMS gives the customer an opportunity to purchase power that is priced lower than the current applicable price 80% of the time. IEMS is a significant pilot program for improving customer service and a long-range demand-side management tool. This allows the utility access to residential load-profile data with the customers' energy patterns. Furthermore, it can help evaluate the effectiveness of current marketing programs and opportunities to future strategic off-peak load building.

TRANSMISSION LOSSES

The 21.2% transmission and distribution (T&D) losses in India are as high as any developing country. The maximum tolerable level of T&D losses suggested by World Bank Report No. 6 on Optimization of Electric Power Distribution Losses is 15.5% with a target level of 8.25% (24). The T&D losses in the European and North American countries range from 5.5% to 10.6%. T&D losses consist of technical losses and commercial or unaccounted losses. The technical losses are due to energy dissipation in the conductor and equipment used for the transmission and distribution of power. The commercial losses are attributed to intentional acts of unscrupulous individuals resorting to pilferage of energy and energy meters becoming defective due to poor quality (24).

Remedies for the Reduction of Losses

In developing countries, the present practice of choosing small conductor sizes for distribution feeders for the low-capital-cost criterion must be avoided. Changing the existing distribution lines with appropriate higher sizes can bring down the losses by 25% to 50%. Reconfiguring networks and balancing loads among substations through the addition of small feeder segments can reduce losses by 20% to 25% and requires a minimum capital investment. By changing the existing transmission lines with higher sizes and upgrading the existing voltage levels, the transmission line losses can be brought down to nearly 2%.

The power factor of the system is lowered by the use of equipment like induction motors and ballasts. By installing shunt and series capacitors, the feeders will be capable of delivering more power and improve the voltage level. The creation of special squads of inspection of service connections and detection of pilferage of energy can prevent theft of energy to a great extent. Finally, the money spent for the reduction of T&D losses will be paid back within a few years.

INTEGRATED RESOURCE PLANNING AND UNIT COMMITMENT

The concept of integrated resource planning (IRP), which evaluates demand-side management (DSM) and supply-side management (SSM) simultaneously and attempts to optimize the mix of these alternatives, has become widely accepted in recent years. According to Chen, Lee, Breipohl, and Adapa (25), IRP is a new and evolving process that consistently assesses various demand and supply resources to meet customer energy-service needs at the lowest economic and social costs. IRP involves deliberations among utility planners and executives, public utility commissions, and customers. These deliberations lead to development of a plan that will ensure reliable and low-cost service to customers, financial stability for the utility, a reasonable return on investment for shareholders, and protection of the environment.

A utility begins IRP by developing alternative forecasts of future electric loads. The utility assesses the costs and remaining lifetimes of its existing resources and identifies the need for additional resources. Next, the utility assesses a broad array of supply, demand, transmission, distribution, and pricing alternatives that could satisfy any foreseen need for more electricity. Such uncertainty analysis helps to identify a mix of resources that meets the growing demand for electricity, is consistent with the utility's corporate goals, avoids exposure to undue risks, and satisfies environmental protection criteria. Because the resultant mix of resources must meet so many criteria, the utility seeks advice from its customers and the public utility commission throughout the process. Finally, the utility prepares a formal report that presents the preferred resource plans and the reasons to choose the best mix of resources.

Unit commitment determines a schedule for optimum startup and shutdown of thermal units that minimizes unit startup costs subject to generation objectives, predicted area requirements (load forecast), security (spinning reserve requirements and off-system capacity), and operational constraints (unit minimum up and down times, limits, ramp rates, maintenance, and derating schedules). The operating cost is defined as the sum of production, startup, shutdown, and maintenance costs. Production cost is calculated by the use of input and output curves adjusted by fuel prices.

Demand-side management usually includes the direct load control (DLC) and interactive energy management systems (IEMSs). The DLC allows utilities to control the loads of water heaters, air conditioners, and other devices. The controllable load of DLC is not an interruptible load in the usual sense but is a deferrable load (i.e., once the supply is restored, the load will try to recover its internal energy balance and thus there will be increase in demand). This phenomenon is known as payback. The IEMS allows the customers to control their load voluntarily by altering use of electricity in response to price signals. The unit commitment can be handled in the following two ways:

1. Given the hourly obligation of the generating system, a unit commitment schedule is determined based on the resource (i.e., fuel, emission) dispatch prices of the system.
2. Given a unit commitment schedule, the proposed method is used to determine the DLC dispatch schedule. Based on the DLC dispatch schedule, the hourly obligation of the generating system is modified.

This two-stage process will continue until the operational cost converges. A close coordination between DLC dispatch and unit commitment can result in additional savings. These additional savings are significant when the DLC capacity can be used as part of system spinning reserve capacity.

IRP is relevant to load management because the DSM and SSM programs can reduce the need for expensive new power plants. IRP ensures a reliable and low-cost service to customers and financial stability for the utility with public participation.

ELECTRICITY TARIFF STRUCTURE

The electricity tariff design is a worldwide effort aimed at recovery of the following charges:

- Interest and depreciation charges on investment (demand charge)
- Fuel costs or energy-related expenses (fuel cost)
- Statutory return (energy or kilowatt-hour charge)
- Other charges (power factor, tax, facilities, etc.)

It is also common to find different rates charged for the summer and winter months. State regulatory commissions have directed the application of time-of-day or time-of-use rates. Recently, many utilities have offered additional rate options to influence temporal use patterns.

Developing Countries

Electricity pricing based on engineering economics is perhaps the only aspect of management of the power supply industry that could not be successfully implemented for reasons beyond the control of managers in developing countries. Most utility companies do not earn sufficient revenue to meet the interest and depreciation liabilities. The gap between the revenue realized and the cost of generation can be reduced by lowering the production cost, increasing the revenue realized, or both.

A comparison of the existing tariff rates with the cost of production shows that industrial customers are paying a reasonable rate, commercial customers are paying more, and domestic and lift irrigation customers are paying a concessional price. A reasonable tariff structure could reduce the financial difficulties. Also, this could force underpriced tariff customers to conserve power.

Power Fluctuations

Until recently, utilities resorted to distribution system voltage reduction as a measure of reducing the system load during emergency losses of major generation capacity or transmission capacity from storms or other causes. Utility voltage reduction is commonly termed "brownout." Tests have proven that voltage reduction measures reduce utility load. A voltage reduction strategy is used, possibly to defer additional power installation, but the growth of this practice for reasons other than emergencies is yet unknown. There is good reason to believe that the practice will grow as a normal operating procedure. An alternative, but far more drastic, measure is the use of rotating blackouts, in which power is switched off for short periods, usually for 2 h per circuit. In the event of rotating blackouts, the negative effect on industry and commercial buildings will far exceed the momentary savings of reduced consumption, and blackout is therefore undesirable in comparison to a brownout condition (26).

Utility voltage reduction on user equipment for prolonged periods can affect operating efficiency and cause equipment failure. Reduction values of $2\frac{1}{2}$, 5, $7\frac{1}{2}$ percentages of voltages are within an acceptable range that a utility might consider. These reductions, however, could shorten fluorescent lamp life, induce damaging heat to motor coils, reduce output of resistive heating equipment, and render sensitive electronic devices, such as computers, production control units, and medical and diagnostic instruments, useless to the consumer.

In developing countries, as per electricity rules and regulations, reducing the voltage and frequency within limits was allowed until recently. The utility companies operated their system with undervoltage and underfrequency conditions consistently during peak hours. During off-peak hours, the utility companies operated with a higher frequency and voltage; however, low operating frequency is harmful to turbines and synchronous motor and will upset their functioning and cause failures quickly.

The use of power conditioning equipment like voltage stabilizers, isolating transformers, uninterruptible power systems (UPSs), surge protectors, and harmonic compensators with filters is vital to protect modern electrical equipment under severe power fluctuations.

ENVIRONMENTAL ISSUES

The generation of electricity produces serious environmental consequences because of the burning of fossil fuels. Power plants are responsible for a large proportion of emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2), and nitrogen oxides (NO_x). According to Hirst (27), electric utilities account for one third of the CO_2 and NO_x, and two thirds of SO_2 emissions in the United States. In addition, utilities are responsible for thermal pollution of lake and river waters used for cooling in power plants, the disposal of nuclear fuel wastes, coal ash, and the environmental damages associated with coal mining and oil and gas production. According to Henry (6), every kilowatt-hour of thermal electricity generated produces an average of 5.3 g of SO_2, 2.8 g of N_2O, and 0.7 kg of CO_2. These numbers vary widely among utilities based on the type of generating equipment that they use.

In developing countries, the height of chimneys in old thermal stations is insufficient and the electrostatic precipitators are working with reduced efficiency. Some of them do not have electrostatic precipitators. The ash content of the coal varies between 30% and 50% in comparison to less than 20% in Western countries. Pollution affects not only the health of persons inside and outside the power plants; it will also upset the biosphere and weather if left uncontrolled.

The coal dust condition is intolerable in many old thermal power plants. The use of water sprinklers would control coal dust. The utilities should use the ash for productive purposes (for example, to construct new roads). Taller chimneys will disburse flue gases over a wide area and will also reduce harmful heating of the atmosphere. Effective pulverization of coal, emulsification of oil sprays, and improved combustion technologies will not only improve fuel-burning efficiency, but will also reduce the unburnt particles polluting the atmosphere. The old thermal stations must install the new electrostatic precipitators of a required efficiency to limit the pollution. These remedial measures could drastically reduce the pollutants, improve energy production, and decrease energy shortage problems in the future.

SUMMARY

Power has become an essential part of our everyday lifestyle, and the responsibility for power rests with everyone who consumes energy. The economy and the desire to improve the environment demand that we be wise when making decisions. This wisdom must be practiced by power companies as well as by individual consumers. Utility companies must search out and utilize every technology and system update that will increase their efficiency, and consumers must not be wasteful in energy use.

Load management modifies the system load shape via direct load control, the creation of off-peak loads, and the shifting of peak-time loads to off-peak hours. Alternative pricing attempts to encourage customers to alter their load demand pattern in such a way as to avoid peak load hours. Energy conservation programs reduce electricity use during all hours of the day. Reducing peak demand minimizes the costs associated with operating peaking units and/or delays the need for new and costly generation and transmission additions to meet system reliability requirements. Solar collectors, wind turbines, and heat pumps are all good ideas, but individuals must be systematic in analyzing their needs and then choose the correct technology or system that will best aid them in achieving desired goals. Power companies may also choose to use supply-side techniques to achieve their load objectives.

Improving the efficiency with which electricity is used can save money for US electricity consumers, reduce the need to build new generation and transmission facilities, enhance financial performance of utilities, reduce emissions of greenhouse gases and other pollutants, increase economic productivity, improve utilities' relation with their customers and regulators, and enhance economic competitiveness. If utilities adopt DSM and SSM programs to reach 5% of their customers each year and cut the use of electricity by 20%, electricity growth and consumption will be cut in half (imply most ambitious program implementation) during the next 20 years. Electric bills would drop by $60 million a year (in 1988 dollars). Such electricity savings would sharply reduce air pollution levels. Total US emissions of CO_2 would be cut by 10%, easing the possible threat of global warming. Emissions of SO_2 and NO_x would be cut by 18% and 9%, respectively, reducing the problem with acid rain. Only through the cooperative efforts of state and federal governments and public utility commissions can the electric utilities increase electrical efficiency and realize these environmental benefits throughout the world.

Electricity helps feed, heat, cool, transport, entertain, and even heal. A kilowatt-hour saved is more than a kilowatt-hour earned. Load management makes electricity do more by using it better. Utilizing the proper light bulb is just as important as developing a functional superconductive system. We can refuse to accept the responsibility and thereby pay the consequences; or we can work toward the same goals and reap the benefits of an efficient energy-consuming society. Load management could force utilities to become globally competitive and respond to the needs of the twenty-first century.

APPENDIX 1. SELECTION OF ENERGY EFFICIENT MOTORS

The selection of energy efficient motors can be achieved using MotorMaster. MotorMaster is a software package and was developed by the Washington State Energy Office and funded by US Department of Energy and Bonneville Power Administration to aid in the selection of energy efficient motors. The database contains motor technical data from 18 motor manufacturers. This technical data includes full and part load efficiency, rated speed, power factor, torque, rated current and voltage, service factor, frame size and enclosure type. Vendor information such as manufacturers' name, model number, list price and warranty are included (28).

MotorMaster generates a list of available models required for the specific type of motor needed with efficiency, performance and cost. MotorMaster calculates the difference in energy and demand usage between standard and energy efficient motors and display kWh, kW, and dollars saved per year. It also estimates the savings in energy and demand charges and projects the simple payback period if the energy efficient motors replace the existing standard motors.

Acceptable payback periods are realizable over a large HP range if energy efficient motors are purchased to replace the standard motors for a new installation or where the standard motor has been deemed beyond repair. The payback could result in unacceptable periods for a true retrofit applications if not supported by management programs (28).

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G. Thomas Bellarmine
University of West Florida
N. S. S. Arokiaswamy
Tamil Nadu Electricity Board