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TEXTILE AND FIBER INDUSTRY

Until recently, the United States reigned as one of the largest textile manufacturers in the world. Today, however, the situation is much different. Textile manufacturing technology has advanced tremendously in the past two decades, and the U.S. textile machinery industry has been greatly affected by the growing competition in Europe, Mexico, and the Far East. This shift has placed the U.S. textile manufacturers in the position of needing to update their older machines and operational practices in an effort to keep up with the growing European and Asian industries. Now, with competition for market share having grown so intense, any advantage must be seized, including reduced operating costs. Areas that have received little interest from the manufacturing companies in the past, such as energy efficiency, drive-system reliability, ease of motor replacement, and availability of spare parts, are beginning to be recognized for their significant influence on operating costs and are starting to receive the attention formerly given only to production improvements.

Electric motors convert approximately 70% of the total electric power consumed by industrial customers in the United States. Improving the efficiency of electric motors provides the single largest opportunity for electric energy savings in the textile industry. Typical motors consume five to ten times their purchase price in electric operating costs each year. Energy conservation measures such as energy-efficient motors provide a simple payback period of less than two years with continual average savings up to 5% in electricity costs thereafter. Adjustable-speed drives can provide additional energy savings along with significant increases in product quality.

Process Description

Figure 1 shows the various segments of the textile manufacturing process. Natural fibers include cotton, hemp, and silk. Manufactured fibers include acetate, triacetate, acrylic, nylon, polyester, polypropylene, and rayon.

Electric-System Loads

Electric Load by Process Area. Table 1 illustrates the distribution of electric load by process area in a typical manufactured fiber plant. Note that approximately 34% of the total load is associated with the production and distribution of chilled water for air conditioning.

Electric-System Efficiency. A method of representing the electric system efficiency is shown in Fig. 2, which illustrates the situation where only approximately 81% of the electric energy entering the facility is finally available for useful work to the end user. The result can be the waste of several million kilowatthours each year, at a cost of hundreds of thousands of dollars to the facility. This does not include the additional costs associated with the increased air-conditioning capacity required to remove the heat resulting from this lost energy.

Table 1: Electric System Usage by Function for a Typical Manufactured-Fibers Plant

	Percent of total Load[a]
HVAC fans	13
Chillers	12
Compressed air	11
Texturizing	8
Extruding and metering	6
Quench air	6
Cooling-water pumps	5
Staple spinning	5
Lighting	5
Filament spin draw	4
Chilled-water pumps	3
Chip drying	3
Staple drawing	3
Polymerization	2
Filament draw twist	1
Staple tow drying	1
Filament spinning	1
Waste treatment	1
Nitrogen, inert gas	1
Cooling-tower fans	1
Beaming	1
Miscellaneous	7
Total	100

[a]Rounded to nearest percent.

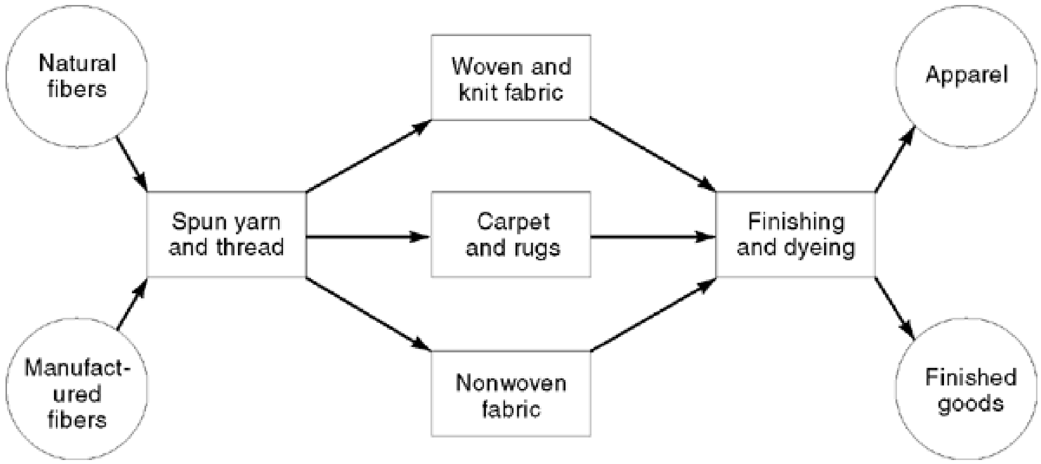

Fig. 1. Textile manufacturing process.

The system diagram approach illustrated in Fig. 2 allows for quick identification of those areas most likely to be potential candidates for energy savings. For example, the low efficiency of 65% for the sync motors being driven by the inverter may be improved with an updated drive system featuring a *PWM* type of waveform output.

Power Distribution System Design. The power costs in a textile or fiber-producing facility can be as high as 22% of the production costs. Thus, careful consideration should be given to decisions regarding utility supply voltage, utility contracts, and power distribution system (*PDS*) design. Various design criteria are covered in the relevant articles in this encyclopedia and in the reading list. In particular, the reader is directed to the IEEE Color Book Series. Since the typical facility is divided into departments, the *PDS* is usually designed to support these departments with individual feeder(s) and distribution transformer(s). With heating, ventilation, and conditioning (*HVAC*) and compressed-air requirements being a major portion of the electric load (see Table 1), the facility's utility department is usually located near the incoming power source, typically the electric power utility's main substation. The transformer(s) and electric switchgear may be owned by either the electric power utility or the facility.

Power Distribution Systems

The term *power distribution system* describes an arrangement of electric equipment and components installed in a manufactured fiber or textile-processing facility that provides the necessary electric power to operate processes or to provide the desired service in a safe and reliable manner. The components usually include, but are not limited to, the following elements:

- Transformers
- Conductors (wire, cable, or bus duct)
- Switches
- Protective devices (fuses, circuit breakers, and relays with voltage- and current-sensing elements)
- Metering (either electromechanical or electronic)
- Line reactors, harmonic filters, and resistors
- Power-factor correction capacitors
- Motors, drive systems, power and lighting panels, heaters, lights, and other system loads

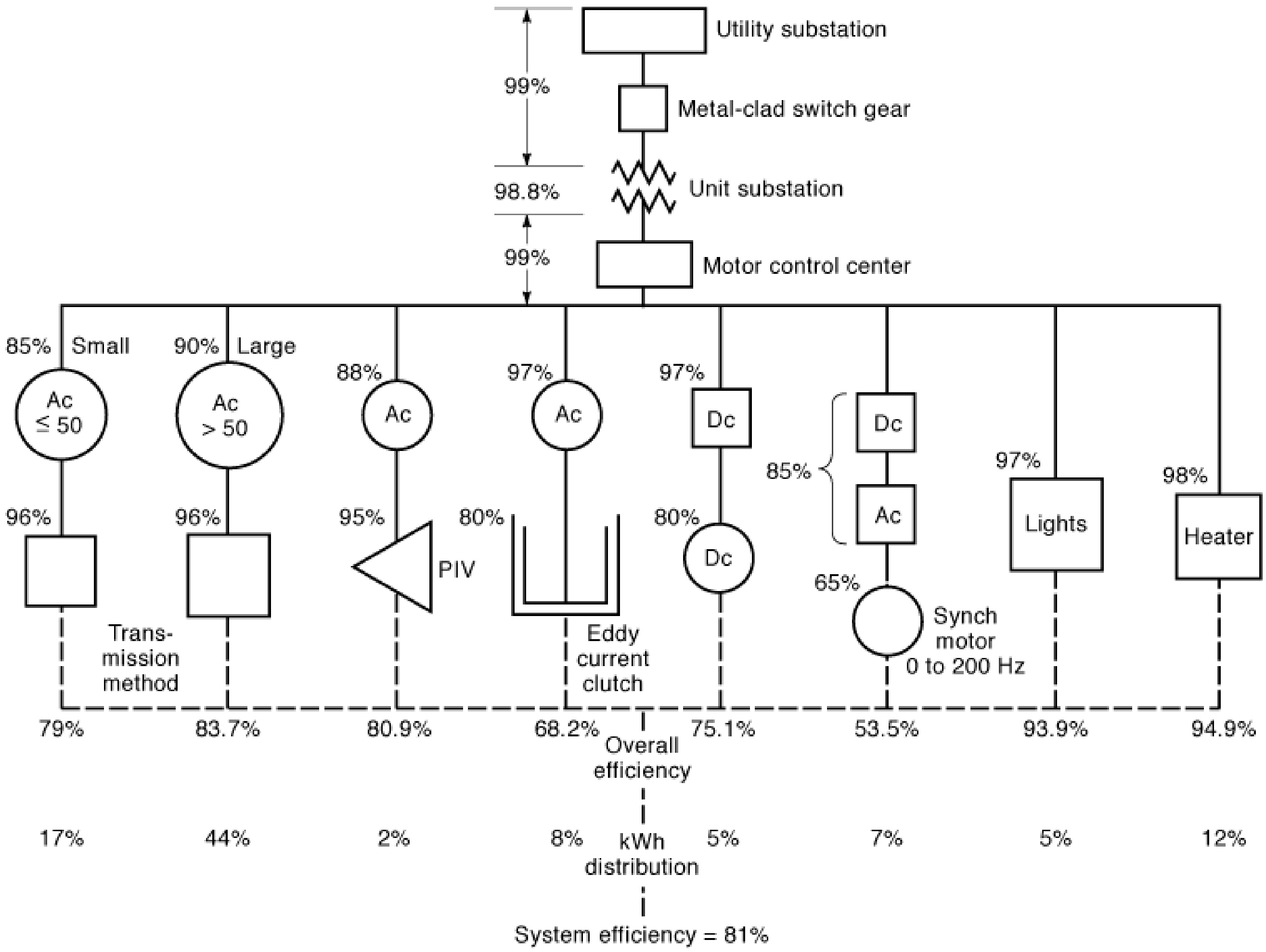

Fig. 2. Use of block diagrams to detail the efficiency of the plant electric system.

These components are arranged to meet the needs of a facility. The continuity of production is only as reliable as its electric distribution system. A variety of basic circuit arrangements are available for a *PDS*. Selection of the best system or combination of systems depends upon a facility's needs. In general, system costs are increased with improved system reliability, and the maximum reliability per unit investment is achieved by using properly applied and well-designed components.

Power Distribution System Criteria. Several criteria are considered when a *PDS* is designed and installed, but none are more important than safety and reliability. Safety, of life and property, is the top priority in the design of any *PDS*. Safety to personnel can have no compromise, with only the safest system being considered.

The required reliability of service is dependent on the type of plant process operation. Some facilities can tolerate interruptions, while others require a high degree of service continuity. A properly designed *PDS* is engineered to isolate faults with a minimum disturbance to the system and to give maximum dependability consistent with the facility requirements and justifiable cost.

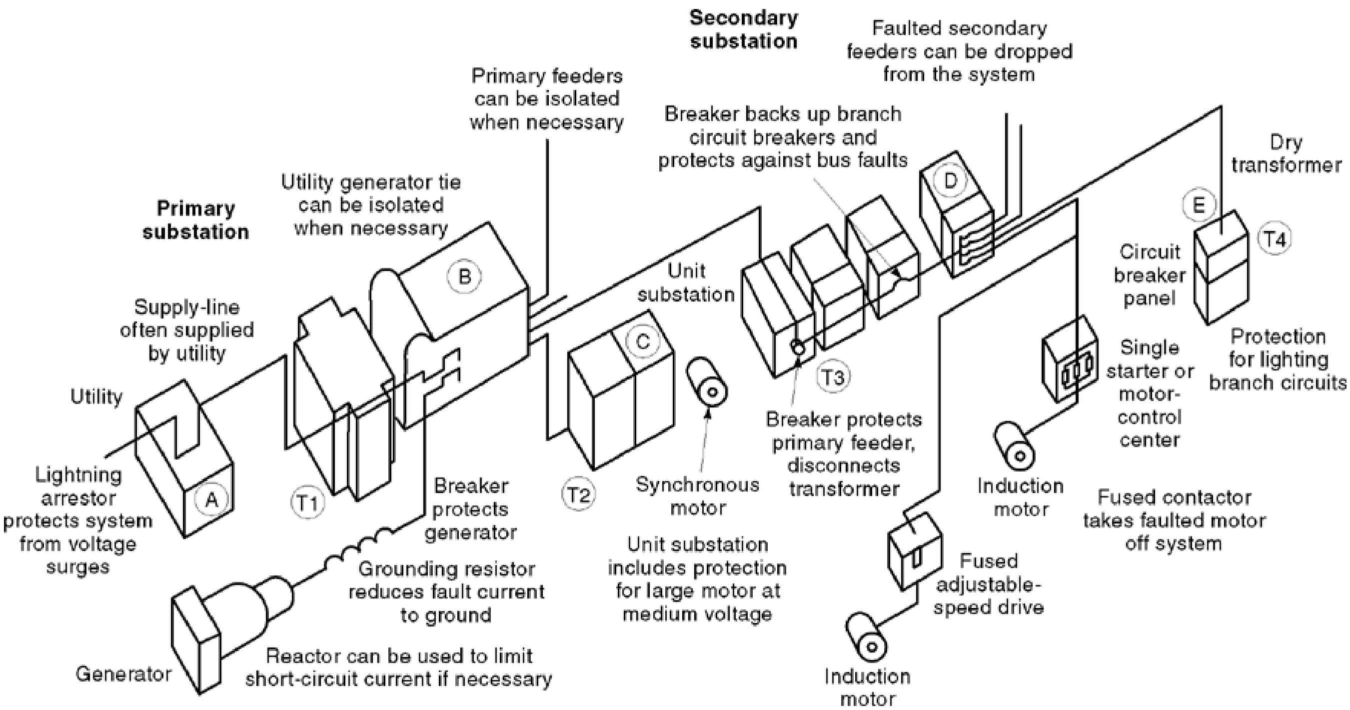

Fig. 3. Electric power distribution system.

The One-Line Diagram. A complete one-line, or single-line, diagram in conjunction with a physical plan of an installation should present sufficient data to plan, evaluate, and maintain an electric power system. This type of diagram is so called because one single line is used to represent the three phase conductors and the neutral, or grounding, conductor. A simplified electric *PDS* for a typical manufactured fiber or textile industrial plant is shown in Fig. 3. Each basic piece of equipment is shown as a box. The incoming supply power from the utility (at the left side of the diagram) is shown feeding the primary substation transformer, T1. If T1 is owned by the utility, the primary feed will be at one of several high voltages such as 35 kV, 69 kV, or 100 kV. The secondary of T1 is commonly at one of several medium voltages such as 6.9 kV, 12.47 kV, 13.2 kV, or 15 kV. This is usually the feed voltage to the various secondary substations in the facility. Large individual—200 horsepower (hp) and larger—synchronous or induction motors may be fed by an individual substation, such as T2, at one of several medium voltages such as 2300 V or 4160 V.

Further along in the system, the remaining motor loads are usually fed by one or more secondary substations, such as T3. The most common secondary voltage is 480 V, with a grounded wye secondary transformer connection. Lighting and office power circuits are commonly supplied from a lighting panel powered by a small (10 kVA to 45 kVA) dry-type transformer, T4, with a primary rated at 480 V and a secondary at 208 V and 120 V, connected in a grounded wye configuration.

Some lighting circuits are operated at 277 V obtained between the phase and neutral conductors of a 480 V wye-connected secondary, supplied through a three-phase 480 V circuit breaker connected directly to the secondary side of transformer T3. The 277 V is the value obtained from the 480 V phase voltage divided by the square root of three (1.732), which is used when working with three-phase power systems. Using 277 V saves the cost of transformer T4 and cuts system cost by reducing copper wire sizes and allowing more fixtures to be placed on a circuit. Using 277 V lighting circuits, however, requires that higher voltage-rated circuit breakers, ballasts, and switches be used.

Transformers are very efficient pieces of equipment, usually in the range of 95% to 98%. The purpose of a transformer is to change voltage from one level to another. The first question is whether a transformer is needed at all. A transformer is almost never turned off. The expected life of a distribution transformer is 30 years to 40 years if operated at full load for 365 days each year. Just connecting a transformer to a distribution system results in energy being used by the transformer due to the losses from primary magnetizing power. The amount of energy required depends on the supply voltage. Losses with no load on the transformer secondary increase or decrease as the voltage increases or decreases, being approximately proportional to the voltage squared. These no-load losses are not affected by the amount of load being supplied by the transformer. So the no-load losses affect the electric bill by adding power to the kilowatt demand charge and electric energy to the kilowatthour (energy charge) portion of the electric bill.

Transformer load losses are caused by the current flowing through the primary and secondary coil wires. A distribution-transformer peak load is usually coincident with the facility peak, so the peak loss can be used to determine the demand portion of the electric bill. Temperature ratings of transformer insulation are based on the temperature rise, given in degrees celsius. Energy savings can be obtained over the estimated 30 year transformer life by using a lower-temperature-rise design and insulation. For example, an 80°C rise transformer will be more efficient than a 140°C rise one, since less heat is generated within windings. Of course, the cooler transformer initially will cost more to purchase. The economics will depend on transformer cost vs. efficiency and the cost of electricity at the facility. An economic evaluation will show if this energy conservation measure is cost-effective.

In cases where more than 50% of the transformer load is nonlinear, consideration should be given to specially designed, *K*-factor transformers. This type of transformer accommodates the higher temperatures due to harmonics, as well as higher than normal neutral currents. *K*-factor ratings of *K*-4, *K*-13, and *K*-20 are available. But the higher the rating, the higher the accommodation for harmonics, and the higher the cost. For most facilities a *K*-13 rating is sufficient. Permanent metering of voltage, current, power (in kilowatts), and electric energy (in kilowatthours) can be installed in locations A through E in Fig. 3. Potential transformers (*PT*s) and current transformers (*CT*s) are always used in locations A, B, and C, and also may be used at D and E. Portable survey meters must be connected to the secondary terminals of these instrument transformers at locations A, B, and C, and may be direct-connected at D and E. If the clamp-on *CT* supplied with the survey instrument has an insulation rating of 600 V, the clamp-on can safely be attached around energized conductors at locations D and E. When portable survey metering is connected to the secondary terminals of potential transformers and current transformers at locations A, B, and C, the appropriate multiplier must be included to reflect the ratio factor of the transformers. Any time changes or modifications are made to the *PDS*, consider installing additional metering to provide necessary data for energy management decisions.

Experience shows that a 1% to 2% energy reduction can be achieved after meters are installed just by communicating the resulting use information to end users. Up to a 5% reduction can occur when the users then become proactive toward better managing their energy. Ultimately up to 10% reduction can be achieved when metering is tied directly to the process through a programmable logic controller or distributed control system, in a closed-loop automated process control arrangement. The single-line diagram also can be used to show future additions. The actual drawing should be kept as simple as possible in a schematic diagram, and need not show geographical relationships.

Electric Metering

Nothing can be managed until it is measured, and measuring use of electric energy is crucial to bringing its costs under control. Adding submetering to otherwise unmonitored electric systems can decrease energy use by

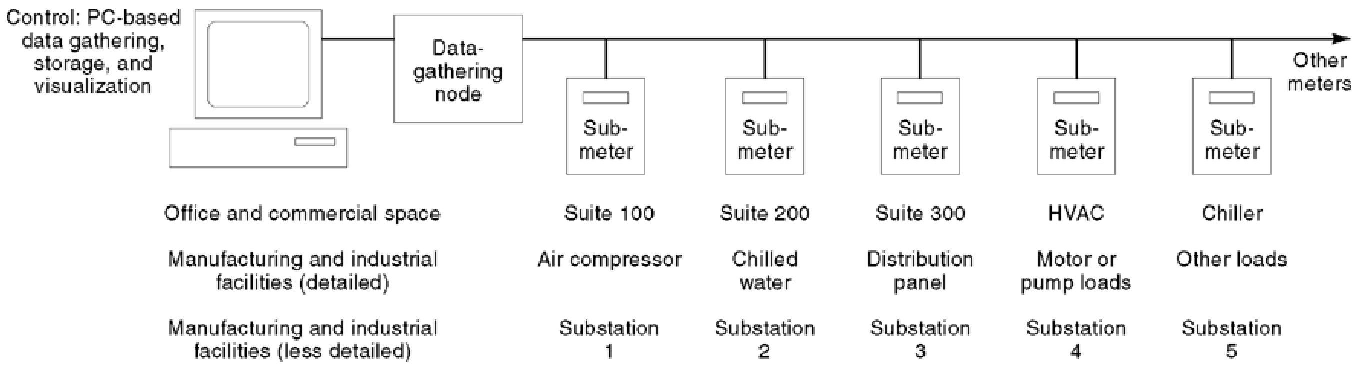

Fig. 4. Electric systems with submeters. The number and location of electric submeters should be sufficient to account fully for virtually all electric energy consumption. For office and commercial space, one meter at each tenant distribution panel, plus one on each shared resource (such as a chiller) should be sufficient. For manufacturing and industrial facilities, the number and location of meters is more a function of the desired level of detail in tracking and reporting. Facilities that require rigorous detail should have one meter per air compressor, chilled-water system, or other shared resource; a meter at each distribution panel; and one for each motor 100 hp or larger. For other facilities it may be appropriate to have fewer meters, located at substations. This approach will track overall electric energy use, but offer less detail.

a few percent through increasing awareness, assigning accountability, and allowing follow up. However, despite this significant potential for energy savings, relatively few facilities take advantage of electric submetering. One utility estimates that only 2% to 5% of manufacturing facilities currently submeter, although education is starting to increase that number.

For many facilities, the amount of electricity used in a given period is available only from one source—the utility's electric meter, located at the main electric disconnect switch. It can be an extremely difficult, tedious, and even futile endeavor to use utility meter readings of kilowatthour consumption (often a very large, single number) in allocating energy costs to specific activities or practices.

Electric submetering systems vary widely in design. For instance, such a system may consist of a handful of sophisticated meters located at main substation and distribution sites, or it may comprise many meters strategically located to provide information on every load 50 kW or larger. For manufacturing and industrial sites, shared resources (such as chilled water and compressed air) are likely candidates for submetering—although motor, lighting, or process loads may be added, depending on the resolution required for full documentation and allocation of energy costs (Fig. 4).

Submetering of electric distribution systems provides powerful information about how, where, and when electric energy is used. With such information at hand, energy managers are better equipped to make important decisions that will save electric energy and improve efficiency. Having data, however, is only the first crucial step; the information that the data provide then must be put to productive use in order for savings to materialize.

Electric submetering can be used effectively by a wide variety of energy users. Manufacturing companies can use submetering to assign energy costs to individual departments or product lines, thereby taking energy costs out of the "corporate overhead" category, and identifying them as true product costs that can be managed and optimized.

A wide range of products are available for measuring where and when electric power is used. These range from simple kilowatthour accumulators that can be located at electric distribution panels or motor control centers, and from which data must be gathered manually, to multifunctioned, automated, and intelligent electronic meters typically installed at electric substations or distribution centers.

Seven Reasons to Meter. It can be difficult to economically justify electric submetering before the level of energy savings or improved productivity is known. Since electric submetering often must compete for funding with projects that commonly are perceived as more directly relevant to a company's business (such as enhancing a manufacturing line), finding a way to justify submetering can be a key hurdle for facility managers to overcome. However, there are some compelling reasons to install electric submetering, seven of which are presented here:

(1) Verify the accuracy of utility bills.
(2) Allocate energy costs to specific departments or processes.
(3) Assign accountability for energy users.
(4) Determine equipment and system efficiency.
(5) Audit before-and-after energy usage for projects intended to improve efficiency.
(6) Identify performance problems in processes and equipment.
(7) Discover opportunities for potential energy efficiency improvements (useful for planning future projects).

Reason 1: Verifying Utility Bills. Imagine paying every credit-card bill you receive without even considering whether all the charges are really yours. Few bills are taken on faith as much as electric power bills. Month after month, energy bills roll in and are routinely paid by accounting personnel—who can only be expected to spot flagrant and obvious math errors.

Given the many thousand of dollars paid for energy every year by the owners and operators of most manufacturing facilities, catching even a small accounting error (such as in demand charges) might recoup the investment in electric submetering in a short time. Even if no errors are caught by a submetering system, however, being able to independently verify an energy supplier's billing can increase the user's negotiating position and stature.

Reason 2: Allocating Energy Costs. One of the hallmarks of a good manager is knowing how much each of the many elements of a manufacturing process contributes to a product's final cost, whether that product is a manufactured item or heating and cooling in a building. Labor, raw materials, machinery costs, maintenance, and even environmental costs often are included in product cost calculations. However, the cost of electric power often is not counted. It is rare for managers to know how many kilowatthours are consumed by a manufacturing process.

Some common methods for estimating energy allocation (based on square footage of floor space, number of workers or occupants, or the capacity of the electric supply circuits) at least acknowledge the importance of assigning electric costs. However, these methods have the disadvantage of spreading energy savings from one area throughout an entire facility—and therefore provide no incentive for departments within a facility to reduce their own energy use. These methods also provide virtually no guidance for future energy efficiency planning decisions. Figure 5 demonstrates one proven process for gathering and allocating energy information from a submetering system.

Reason 3: Assigning Accountability for Energy Users. Unfortunately, energy efficiency often is low on the list of criteria by which managers are evaluated. In most cases, however, this is the result of inadequate measurement. Monthly energy cost allocations to a department can provide a standard by which its manager's performance can be measured. In the experience of the author, simply making energy efficiency a factor considered in managers' annual evaluations can shave a couple of percent from a company's overall energy expenses through such voluntary measures as turning off lights, *HVAC*, and machinery when they're not needed, and fixing compressed-air leaks.

Case Study. A major fiber manufacturer recently implemented a system of electric submetering in its South Carolina facility. Before acquiring the detailed energy-use data submetering provides, the company knew

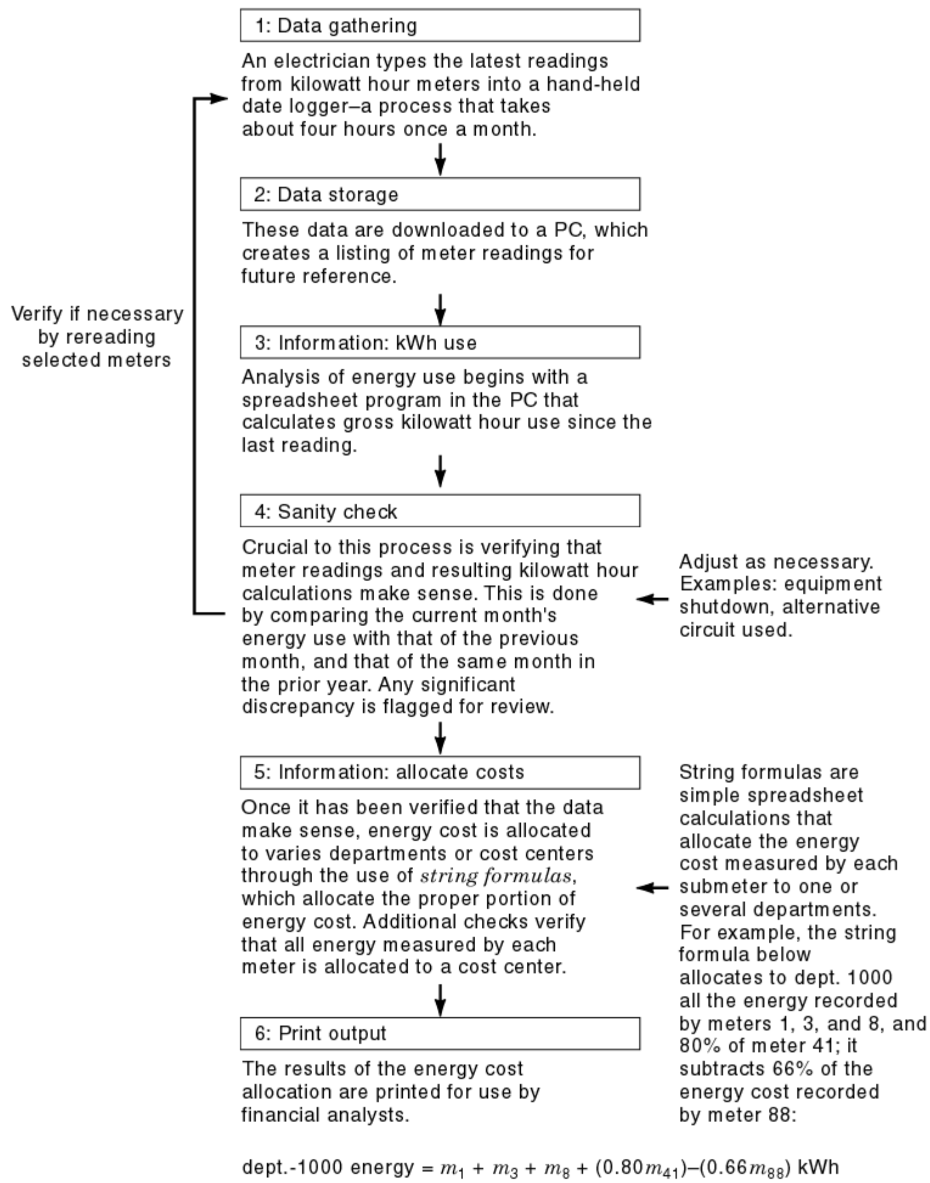

Fig. 5. Energy cost allocation flow chart. One company uses 150 meters and a manual data-gathering process to allocate its monthly electric energy cost.

the facility's overall level of energy use only by a single utility electric meter—the typical approach for many industrial facilities today.

After the installation of submetering (and before follow-up measures were implemented), overall energy use fell by 2% to 3%. The submetering made employees more aware of energy costs, and they began voluntarily turning off lights and equipment when they were not needed. Once submetering data were available and

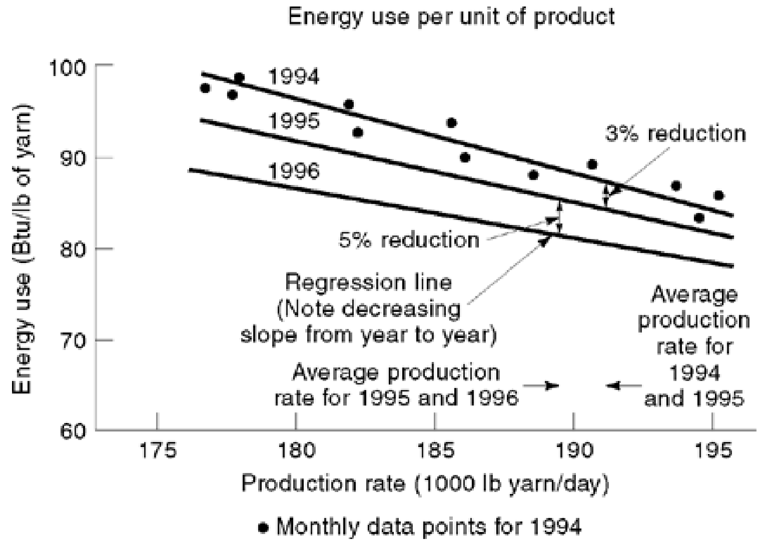

Fig. 6. Measuring continuous improvement of energy efficiency. Once energy consumption data have been gathered, they must be analyzed to provide information useful for evaluation and decision making. Comparing energy use on a "per-unit" basis provides a method to accommodate inevitable variations, such as in the amount of product made in a specific month, or in the number of tenants occupying a rental space. An example from a textile plant is shown here. Energy use and production data are gathered each month from submeters and production records. Over the course of the year, the energy manager uses simple linear regression to plot a line approximating the rate of energy use per unit of production (in this case, per 1000 pounds of yarn) at different production rates. The regression line is revised as new data are added each month. The current year's results then are compared to those from prior years to determine whether energy efficiency has improved. Of particular interest are whether the annual energy-use curves are dropping year to year (indicating steadily improving efficiency per unit), and whether the slopes of the lines are progressively flattening (indicating that "fixed" energy costs such as lighting or *HVAC* also are diminishing). In this case, making managers accountable for energy use resulted in the installation of improved steam traps and more efficient lighting, and in improved scheduling of equipment. This reduced energy use by 3% between 1994 and 1995. Adding adjustable-speed motor drives to *HVAC* fans enabled a 5% reduction in the following year. Also, the slope of each line is flatter than the one before, demonstrating steady reductions in "fixed" energy use.

subjected to analysis, the company incorporated energy efficiency as part of annual performance evaluations for manufacturing superintendents. These managers were directed to reduce energy use per pound of product (see Fig. 6), which resulted in further energy savings of 3% over the next two years due to improved scheduling of equipment and installation of more efficient steam traps and lighting. Overall energy savings of 5% are directly attributed to the company's submetering program.

One way to compare the relative energy efficiency performance of departments is to analyze energy use per unit manufactured, or per tenant occupant. Figure 6 shows one such analysis for a manufacturing department. Such methods allow documentation of continuous improvement of energy efficiency—similar to how other systems document continuous improvement in productivity, quality, or customer or client satisfaction.

Reason 4: Determining Equipment and System Efficiency. Is the energy efficiency of the manufacturing equipment acceptable? The only way to know is through measurement. If electric submeters are positioned strategically on circuits that feed key pieces of equipment, energy managers can develop powerful energy metrics (statistics or benchmark values) for evaluating the performance of existing equipment, as well as in specifying new machines.

For most facilities, the only metric available for evaluating the efficiency of a device or process is the original design specifications and the vendor's claims—both of unknown accuracy. Even when metrics for

Table 2: Energy-Use Metrics[a]

Activity	Resource cost per unit
Compressed air (125 psig)	3.2–4.0 kWh per 1000 standard cubic feet
Central chillers	0.6–1.0 kW per ton, or 0.6–1.0 kWh per ton-hour
Refrigeration (delivered)	1.0–2.0 kWh per ton-hour
Steam boilers (250 psig)	Number 6 fuel oil: 7.1–9.0 gal per 1000 lb steam
	Number gas: 1000–1300 scf per 1000 lb steam
	Pulverized coal: 100–120 lb per 1000 lb steam

[a]Submetering enables energy managers to develop meaningful metrics for the amount of energy used by particular processes or equipment. A useful metric always should put energy consumption or cost in terms that allow ready comparison with other costs of service or manufacturing.

energy use do exist, they are often in a form that is not intuitive (such as kilowatthours per month or year). A better approach is to use submetering to develop energy-use metrics that are meaningful. Some useful energy metrics include energy cost per part or energy cost per pound of product for industrial facilities (Table 2).

Reason 5: Auditing Energy Use. Economic justification and approvals for energy efficiency improvement projects often face an uphill battle because such projects often are not viewed as central to a company's business, and they typically focus on cutting costs rather than increasing production. It is also true that future energy cost savings can be difficult to quantify, making many managers reluctant to invest in submetering. To establish supporting evidence that may help justify future energy efficiency projects, two types of supporting data should be gathered from projects currently in the works. Submetering can supply both of these:

- Before a project: gather measured data that quantify the energy savings opportunity.
- After a project: gather measured data that verify the expected rate of savings.

Even if no energy efficiency projects currently are underway, it is useful to gather baseline information about a facility's energy use (see reason 7). It is helpful (and interesting) to notify employees and occupants when energy benchmarking is initiated. The author has noted improvements of a few percentage points in energy efficiency simply by installing electric submetering in a previously unmonitored area. (See "Justifying the Cost of Submetering" below.) In addition, accurately measuring energy costs can show that decisions made by production or building management staff—not just those of the energy manager—play a significant role in the overall cost of energy for a facility.

Reason 6: Identifying Equipment and Process Problems. Monitoring the energy consumption of equipment and processes can provide useful—and often critical—early warning of undesirable changes. For example, what if an adjustable-speed drive is manually set to operate at full speed, and then is left that way inadvertently? It would be all but impossible to identify that problem among the thousands of kilowatthours reported on a gross facility-wide electric bill. However, periodic checking of a local electric submeter might show that while production in the area did not increase, energy consumption did—thereby alerting operators to look for a cause.

In another example, what if the thermostat on a 50 kW electric space heater malfunctions, causing the heater to operate continuously? At many facilities this problem would be discovered only in the unlikely event that an especially observant operator or maintenance person noticed the unit running unnecessarily.

Submetering can help in early identification of many types of equipment or process problems that are sources of energy loss, including:

- Plugged heat exchanger coils in chiller plants
- Clogging inlet filters on air compressors
- Degradation of (or loss of) lubricant in motors, load bearings, or gear boxes
- Control failures that cause equipment to run continuously or at inappropriate times

Reason 7: Discovering Future Energy Savings Opportunities. Electric submetering can help track down energy savings opportunities by answering two questions:

- Who is using the most energy, and how are they using it? Electric submetering can identify the key users (departments or processes) of electric power in a facility, and provide crucial information about the profile of those loads and their contribution to peak demand penalties. This information can allow an energy manager to focus early on the biggest savings opportunities in each process area, greatly improving the effectiveness of subsequent measures.
- Energy savings compared to what? An ongoing benefit of electric submetering is sound, detailed documentation of a facility's historical energy use patterns. Far too many cost reduction projects have failed to produce expected savings because initial estimates were based on spotty measurements that failed to take into account periodic, seasonal, or unusual factors. Having a solid database of previous energy use to draw upon and compare against can increase confidence in projections of energy savings.

Justifying the Cost of Submetering. In many instances, an electric submetering system can cost from a couple of thousand dollars (for simple monitoring of energy consumption at a couple of locations) to tens of thousands of dollars (for automated reading of several parameters at many locations). This cost has been notoriously difficult to justify economically in retrofit applications, since it is very difficult to quantify economic benefits before the meters are installed. How can an expense today be justified economically by an uncertain return tomorrow?

Energy managers typically have high expectations regarding energy savings and improved operation due to electric submetering. However, it is all but impossible to identify beforehand exactly where potential energy savings are hidden, and how much energy can be saved. Obviously, if an energy manager had that information, necessary changes would have been made long ago.

Potential energy savings from submetering tend to fall into three general categories:

- Savings from "just metering." Telling employees that electric energy use is being measured in greater detail can have the psychological effect of increasing awareness of energy use—thus causing people to notice energy waste (such as lights and computers that are left on, or thermostats that are set too high or low). The rationale is "If someone's going to the trouble of measuring energy, it must be important." In practice, such savings may prove difficult to quantify because they can occur before baseline data are collected, and before cost allocation and auditing are implemented.
- Savings from increased accountability. Additional energy savings can be expected if middle managers are held accountable for knowing, and controlling, energy costs (see reason 3 above).
- Savings from automation. The two points above demonstrate the benefits from "manual" voluntary energy savings, which result from new information and incentives. Additional energy savings can be achieved by automating part of the submetering process, and then linking the functions of process controls to energy-related factors. For example, some manufacturing facilities operate several parallel manufacturing lines. At times of peak demand, the automated control system can shut down some of the lines or noncritical processes, or even warn operators of impending problems (such as the danger of incurring increased demand charges by inadvertently setting a new peak demand threshold).

There is always the chance that a submetering system could pay for itself very quickly—such as by catching a billing error, or by avoiding the failure (and costly replacement or repair) of a crucial piece of equipment. However, since such events are difficult to predict, they should not be considered in the payback calculation. Users should be aware, however, that if a costly event does occur that could have been prevented (or mitigated) by the use of submeters, this unfortunate circumstance can be used as a convincing justification for a submetering expenditure.

For those situations or facilities where energy savings estimates alone are insufficient to justify permanent electric submetering, temporary or portable survey-type systems should be considered. Periodically spot-checking energy use for a department or tenant allows the discovery and correction of anomalies (albeit not as quickly as when permanent meters are monitored continually). Survey meters can be configured in portable test stands that are moved from location to location, allowing many facilities to be checked with one investment in equipment.

The Importance of Follow-up. By themselves, meters do not save money—they only cost money to purchase and install. Hence, the key to maximizing savings is to complement a submetering system with appropriate recordkeeping and evaluation procedures.

- Recordkeeping. This usually involves developing and maintaining a database of energy readings. Such databases most commonly are kept on a PC to facilitate manipulation of data in a way that provides information.
- Obtaining Information. Obtaining useful information from raw data is a common stumbling point in analyzing energy performance. Take the example of a plant that consumes more energy this year than last: is this good news or bad? If the output of the plant has increased significantly, the higher energy consumption could be a natural consequence of greater activity—almost certainly good news. However, if production has remained constant (or has dropped), then there may be a problem. Analyzing data can provide useful answers to these kinds of questions (see reason 3 above, for example).
- Taking Action. Information that does not result in action is all but worthless. Going to the expense and trouble of gathering data on electric energy use and then analyzing it only makes sense if that then feeds a process of continuous improvement, preventative maintenance, and reward for improved performance.

Power Quality Issues in the Textile and Fiber Industry

The following discussion presents topics from selected portions of publication BR-105425, *Power Quality Considerations for the Textile Industry*, by EPRI of Palo Alto, CA; ASDO of Cary, NC; and Duke Power of Charlotte, NC (1). Written permission has been granted for use of these extracted segments.

Power Quality Defined. A power quality problem is any occurrence manifested in voltage, current, or frequency deviations that results in failure or misoperation of plant equipment. Electric power disturbances may be one of many causes of lost productivity. Efforts towards resolving such issues are often cooperative actions among textile plants, electric utilities, and equipment vendors.

Utilities recognize the importance of power quality to their customers. Many utilities have designated "power quality" groups dedicated to helping customers resolve productivity problems related to power quality issues. Such groups can also help customers plan facilities, develop purchasing specifications, and establish installation guidelines so that future power quality problems are minimized.

Economic Relevance. Today's intense global competition in the textile industry makes unprecedented demands on productivity and power quality. In modern textile plants, power quality disturbances can be a significant source of lower product quality, lost productivity, and reduced competitiveness.

It is difficult to estimate the cost of power quality problems. Lost productivity includes the direct costs in wasted raw materials, labor, and restart time, which are easy to evaluate. In addition, indirect costs such as lost business opportunities and missed schedules are difficult to quantify, but also may be significant.

The Textile Industry Environment. Automation and electronic technologies are providing new weapons in the U.S. textile producers' fight to capture global market share. New generations of electricly powered equipment are boosting productivity and improving energy efficiency. More than just another energy source for textile manufacturers, electricity has become a unique and invaluable resource to improve the industry's global competitive position.

Just as microelectronics gave rise to the desktop computers, power electronics opens doors to technologies that are reshaping the role of electricity in the 26,000 fiber, textile, and apparel plants now operating in the United States. In a recent year, textile manufacturers spent some $2.7 billion on capital improvements to upgrade and automate facilities. Virtually all of those improvements included electronic systems. Proactive planning of the power supply system by plant, utility, and equipment representatives is vital to the success of plant modernizations.

Today's textile operations rely increasingly on solid-state electronic systems ranging from microprocessors operating on small fractions of an ampere of current at low voltages to power electronics controlling thousands of volts and hundreds of amperes. Automation and high-speed processes are part of the reason that the textile industry is being transformed into a high-tech industry.

The revolution in the textile industry is improving product quality, increasing production speed, and reducing per-unit production costs. Advanced spinning, weaving, dyeing, and finishing machinery with more responsive process controls offers unprecedented precision and speed. For example, modern air-jet weaving and spinning equipment often operates at four or more times the speed of its conventional counterparts.

Power Quality Challenges. The advanced electronics that make tremendous production gains possible have introduced some new challenges as well. Unlike simpler electric equipment, today's sensitive electronic devices place higher demands on the electric systems of both utilities and textile plants. What were once considered acceptable or minor variations in power may now bring plants to a standstill. In addition, some electronic devices create their own disturbances. For example, adjustable-speed drives may cause unwanted harmonic distortion in a plant's internal electric system that can interfere with other equipment.

In textile plants, equipment overheating often is related to mechanical overloads or failures in cooling mechanisms due to problems such as clogged filters. For example, overheating of adjustable-speed drives (*ASD*s) in one cotton plant was traced to lint-clogged air filters.

Such mechanical difficulties may make equipment more sensitive to power supply variations. Correcting an underlying mechanical problem can restore a machine's intended tolerance for electric system variations. Equipment overheating may also be related to undervoltages, overvoltages, or harmonic distortion. Undervoltages and overvoltages may lead motors to overheat, causing built-in protection devices to shut down the equipment. If the voltage problems are not corrected, the life of the motor may be shortened as well.

Harmonic currents in textile plants are increasing due to the proliferation of power electronic devices such as *ASD*s in production equipment, switched-mode power supplies, and electronic ballasts for fluorescent lighting. The nonlinear characteristics of these and other power electronic devices produce harmonic currents that can cause power system overheating, interfere with communication systems, and trigger equipment malfunctions. Harmonic currents also contribute to high levels of voltage distortion.

Control equipment may be sensitive to voltage sags caused by motors starting or power system short circuits. Although tolerance for sags varies widely, electronic systems may respond to voltage decreases, causing equipment to shut down. Overvoltages also can disrupt process controls, triggering shutdowns, or impair restart capabilities. While shutdowns have major impacts on all textile production processes, the effect on fiber manufacturing is especially severe.

Sources of Disruption. A systematic approach to identifying the source of a power quality disturbance is required. Resolving power quality issues cost-effectively requires imagination and good business sense. While utilities may be one source of power quality variations, causes are frequently also often found within textile facilities. Among the most common sources of plant disruptions are:

- Wiring and grounding deficiencies
- Voltage sags due to starting large motors across the line
- Plant load interactions
- Facility modifications

Sometimes the solution to an apparent power quality problem is simply to tighten a loose connection or replace a corroded conductor. In many cases, just improving wiring or grounding enables equipment to operate without disruption.

As many as 80% of all equipment failures attributed to poor-quality power may result from inadequate electric wiring and grounding or from interactions with other on-site loads. Such difficulties frequently arise when installing new electronic equipment that relies on existing building wiring. Many people mistakenly believe that if electric systems are wired and grounded according to National Electric Code standards, they should have no electric problems. However, NEC standards focus on safety, not system reliability. A building's wiring may comply fully with NEC standards and still be inadequate to support sensitive electronic loads. IEEE Standard 1100, the *Emerald Book*, offers suggestions on powering and grounding electronic equipment in modern manufacturing plants.

In textile plants, voltage sags are among the most common power disturbance and may account for more lost production than any other cause. Such sags may be due to

- Starting large motors in the plant
- Far-away short circuits on an electric utility power line (most often due to lightning)
- Sudden load changes by neighboring industrial plants

The power delivery system from the utility to the textile plant is complex, and power quality disturbances may originate anywhere in this system. Determining the most cost-effective solution requires thoughtful consideration of all possibilities.

Plant load interactions also can lead to equipment malfunctions. When large loads—such as the motors that operate process equipment, air conditioners, furnaces, or elevators—are turned on or off, momentary voltage sags or transient voltages can occur. Such fluctuations often affect the operation of sensitive devices.

If major electronic equipment is installed without upgrading wiring to accommodate higher power use, undervoltage conditions may result. Such conditions can usually be resolved by upgrading electric circuits or adjusting voltage taps on building transformers. Similarly, if old and new equipment are used together, step-up or step-down transformers may be required. In addition, a collection of equipment with similar but different voltage ratings may impose impossible demands on a plant's power distribution system.

Power Quality Tips. *ASD*s require sufficient isolation from the electric system to ensure that short-lived high-voltage transients do not overcharge internal capacitors. If the capacity of a transformer serving an *ASD* is greater than 10 times the capacity of the drive, then external inductors are probably required. This applies to *ASD*s integrated into equipment by the manufacturer as well as stand alone *ASD*s. Equivalent internal drive reactors may be available from manufacturers.

Respect equipment voltage ratings. When old and new equipment are used together, voltage-matching transformers may be needed to restore intended operating ranges. Remember that most modern electronic equipment is never really turned off. Rather, the equipment shifts to a standby condition, where it remembers configurations, keeps time, and performs behind-the-scenes functions continuously. Such functions include enforcing equipment ratings. Process controllers and *ASD*s will disconnect quickly from an out-of-tolerance power system. This makes it very important to coordinate voltage ratings between the utility power supply and all plant equipment, including internal control voltages. Careful specification of all conditions that equipment will experience enables manufacturers to match components correctly with the operating environment. Utilities can provide assistance, such as round-the-clock voltage measurements, before installing new equipment. In a facility with equipment that has a variety of voltage ratings, the allowable voltage range to meet the needs of all equipment is very small. Transformers should be used to match equipment with the voltage supply.

Programmable logic controllers are usually set to handle process anomalies and generally will recover to ensure the integrity of the manufacturing process. Therefore, protecting controllers from power failures with commercially available uninterruptible power supplies (*UPS*s) is an excellent investment. After a brief power outage, process recovery is dramatically improved if the controller does not lose its programming and therefore can assist in the recovery. Installing one general-purpose *UPS* in a plant is economically tempting, but maintaining discipline as wiring applications are added is an ongoing problem. Process-specific *UPS*s are simpler to apply and more straightforward to troubleshoot. For best results, all critical-process programmable logic controllers must be identified and protected with *UPS*s or constant-voltage transformers (*CVT*s). *CVT*s are useful and cost-effective when voltage sags occur much more frequently than power outages.

The adequacy of building electric facilities must be reviewed before replacing older equipment with new technology. High-performance power delivery requires additional care and planning, and merely meeting minimum safety standards will not ensure proper equipment performance. To help customers meet the more exacting power demands of emerging technology, many electric utilities offer electric system planning assistance. Modern electronic equipment must have a neutral conductor that is at least as large as the phase conductors. The rule that permits undersized neutral conductors was intended for motors and heaters, and specifically excludes electronic loads. When replacing equipment in an existing plant, assume that the existing wiring is not adequate and must be upgraded—even if new, energy-efficient equipment seems to require less electric power than the equipment it replaces.

Electric utilities can provide information to help you avoid harmonic resonance problems. When making changes or requesting new electric service, ask about the:

- Maximum available short-circuit current, expressed in amperes
- Normal system impedance, expressed as resistance and reactance ($R + jX$)
- Existence of nearby power-factor correction capacitors that might cause resonance

If there are nearby capacitor banks, the utility can help identify possible resonant conditions due to different switching configurations. A utility may have more than one route to provide electric power to a customer, and any route may include power-factor correction capacitors. The capacitor installations themselves also may have several configurations, adding a layer of complexity to your calculations. Identifying potentially troublesome configurations during planning allows you and your utility to avoid problems.

Making a Power Quality Checklist. Power quality plays an important role in delivering the promise of increased textile industry productivity. Modern textile machinery has various levels of power quality sensitivity, requiring more coordination among representatives of textile plants, utilities, and equipment suppliers. Every segment of the industry must include power quality implications in equipment planning, purchasing, and installation decisions. Key power quality considerations are:

- Planning.

  Set your expectations for equipment performance. Ask your utility for help in identifying power quality concerns. Utilities can provide site-specific characteristics such as expected voltage regulation, reliability, voltage sags, transient overvoltages, and automatic protective device operation. Exchange of protective relaying information is required to coordinate utility and plant equipment properly. Examine your plant electric system characteristics for voltage regulation, reliability, voltage sags, transient overvoltages, and harmonics.

Share the electric characteristics at the point of use (both utility and in-plant characteristics) with potential equipment suppliers.

Evaluate equipment performance, keeping in mind needs required at the point of use. Maximum short-circuit values are insufficient for designing *ASD* and other electronic facilities. Request information from your utility on different likely configurations, and inform your supplier. Address in-plant wiring and grounding requirements. Identify critical process controls and their special power requirements.

- Purchasing.

  Specify the voltage operating range for all new equipment.

  Use transformers when equipment voltage ratings do not match the actual operating environment.

  If required, specify appropriate power—conditioning or ride—through equipment for process machinery.

  *ASD*s may require external reactors or isolation transformers. Modification kits or internal modifications may also be available. Investigate your options, and specify them when ordering equipment.

  Specify cost-effective power conditioning for critical process controls.

- Installation.

  High-performance wiring and grounding is required by modern electronic equipment, and should be included in the installation of replacement technologies.

  For all branch circuits serving electronic equipment, neutral conductors must be at least the same size as phase conductors.

- Follow-up.

  Regularly review equipment performance, and continue the high level of cooperation between plant, utility, and equipment representatives.

  When problems occur with existing equipment, the same high level of cooperation between plant, utility, and equipment representatives is required to identify the most cost-effective solution.

  Documentation of problems is essential to swift evaluation and correction. Disturbance logs that include date, time, description of problem, operation conditions at the time, and other details are most helpful to assess power quality problems. These logs can be used to help make future equipment planning, purchase, and installation decisions.

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