ENERGY MANAGEMENT SERIES

3

FOR INDUSTRY COMMERCE AND INSTITUTIONS

Electrical

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Canada

PREFACE

Much has been learned about the art and science of managing energy during the past decade. Today, energy management is a seriously applied discipline within the management process of most successful companies.

Initially, in the early 1970's, energy conservation programs were established to alleviate threatened shortages and Canada's dependency on off-shore oil supplies. However, dramatic price increases quickly added a new meaning to the term "energy conservation" — reduce energy costs!

Many industrial, commercial and institutional organizations met the challenge and reduced energy costs by up to 50%. Improved energy use efficiency was achieved by such steps as employee awareness programs, improved maintenance procedures, by simply eliminating waste, as well as by undertaking projects to upgrade or improve facilities and equipment.

In order to obtain additional energy savings at this juncture, a greater knowledge and understanding of technical theory and its application is required in addition to energy efficiency equipment itself.

At the request of the Canadian Industry Program for Energy Conservation, the Commercial and Institutional Task Force Program and related trade associations, the Industrial Energy Division of the Department of Energy, Mines and Resources Canada has prepared a series of energy management and technical manuals.

The purpose of these manuals is to help managers and operating personnel recognize energy management opportunities within their organizations. They provide the practitioner with mathematical equations, general information on proven techniques and technology, together with examples of how to save energy.

For further information concerning the manuals listed below or material used at seminars/workshops including actual case studies, please write to:

Business & Government Energy Management Division
Energy Conservation Branch
Department of Energy, Mines and Resources
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INTRODUCTION

Over the past 100 years, the impact of electricity has been felt in all aspects of Canadian society. Electricity provides comfort and security in our homes, schools, offices, and industrial plants; in our public institutions, hospitals and places of entertainment and recreation. It does this by controlling other forms of energy or by providing energy for lighting, heating and a wide range of electrical equipment.

At the turn of the 20th century, the productivity of our industrial plants was greatly enhanced through the introduction of the electric motor which, in most cases, replaced cumbersome steam engines or water wheels. Nearing the 21st century, the increased use of electricity and electrotechnologies such as lasers and microwave equipment, combined with industrial computerization and robotics, are revolutionizing industries who wish to remain efficient, productive and hence competitive in an increasingly global environment. At the same time, the development of alternate energy sources is also advancing. Photovoltaics and wind energy equipment are supplying electricity for specific uses in remote locations, which includes uses such as battery charging in vehicles and marine craft.

Purpose

The purpose of this energy management module is to assist those responsible for the maintenance and operation of electrical systems in identifying energy management opportunities which may contribute to improved operating efficiencies, improved comfort and lower operating and energy costs.

This purpose will be presented through the following:

- Review the most pertinent fundamental energy management principles involved with a variety of electrical equipment and systems.
- Focus on those areas which are likely to contribute the most towards reducing system losses and the overall electric bill.
- Describe some of the equipment and electrical systems used in commercial, institutional and industrial sectors.
- Identify potential energy management opportunities.
- Present a number of worksheets which will assist in calculating energy and cost savings.

Contents

A description of the contents of this module is as follows:

- *Fundamentals* discusses electrical theory, metering and rates. It also deals with those factors which are most likely to help improve the efficiency of an electrical installation and reviews the basic calculations necessary to evaluate the operating efficiency of the main parts of an electrical system.
- *Equipment* provides an overview of the main types of electrical equipment, their capacity ranges, and the advantages and disadvantages of each type.
- *Energy management opportunities* lists items which deserve attention in energy or diagnostic audits. In this section, energy calculations illustrate some of the methods used in quantifying both potential energy losses and the benefits of corrective measures by providing worked examples.
- *Appendices* includes a list of abbreviations, tables, worksheets and a glossary of terms.

FUNDAMENTALS

The basic function of any electrical system is to transfer energy from a generation source to an end-use application. To the user, the energy found in electricity is not as important as how this energy can be transformed into light, heat and power for electrical devices. Central to this transfer of electric energy from the source of supply to the application is the flow of electric current.

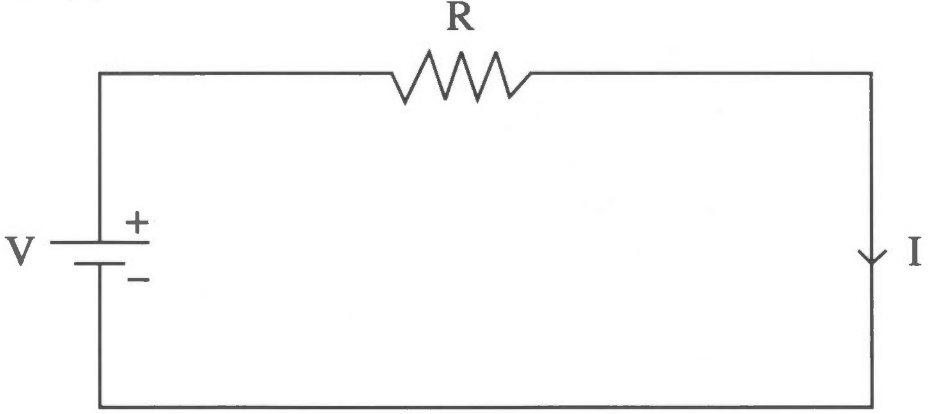
An electrical circuit is a path along which this electric current flows. This circuit is composed of wire conductor, that is, a substance which has within its metallic structure loosely bound electrons which can move or "conduct" electricity. In order for an electric current to flow along a conductor between two points, there must be a difference of potential between them. This difference is measured in volts.

Direct Current (dc)

Direct current is an electric current that continually flows in one direction. This flow can be steady or pulsating. According to Ohm's Law, the amount of steady current flowing in a circuit is equal to the voltage, divided by the resistance of the circuit.

$I = V/R$

Where,
I= current (A)
V= voltage (V)
R= resistance (Ω)



Typical dc Circuit
Figure 1

In this simple circuit representation, electric power is the product of current and voltage.

$P = V \times I$
where
P = Power (W)

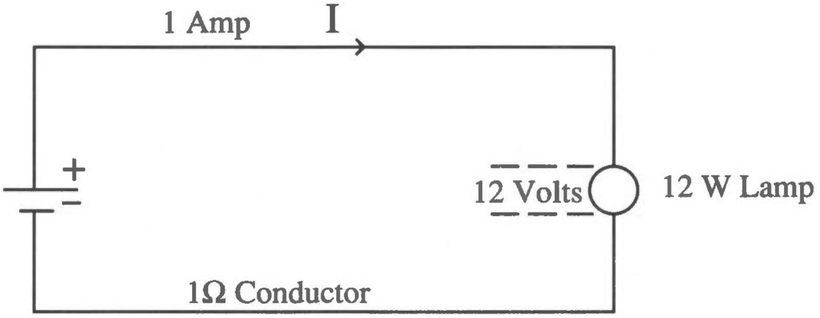
The power expended can also be expressed as follows:

$P = I^2 \times R$

This equation demonstrates that the power expended in a piece of conductor is the product of the square of the current, multiplied by its resistance. In order to limit electrical losses in circuits (usually in the form of heat) when transmitting a given amount of electricity, the voltage should be kept as high as practical and safe, so as to keep the current as low as possible.

For example, a 12 watt lamp connected to a 12 volt circuit will draw an electric current of 1 amp (A).

$P/V = 12/12 = 1A$

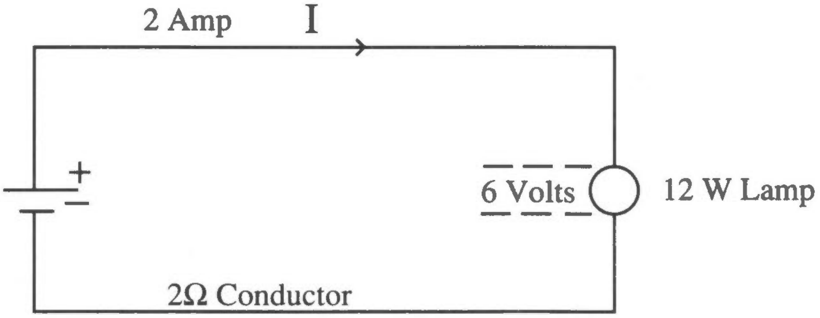


Losses = I^2R = 1Watt

Figure 2a

Likewise a 12 watt lamp connected to a 6 volt circuit will draw an electric current of 2 amps.

$P/V = 12/6 = 2A.$



Losses = I^2R = 4 Watts

Figure 2b

Assuming that the conductor has a resistance of 1Ω , the power loss in each case is:

at 12 volts:
$I^2 \times R$
$= 1^2 \times 1$
= 1W; and

at 6 volts:
$I^2 \times R$
$= 2^2 \times 1$
= 4W.

It can be seen from the above calculations that by halving the voltage the result has been a quadrupling of the heat loss in the wire.

In a dc circuit, electric energy is the product of power (P), multiplied by the time (T) during which it is consumed. This is expressed in watthours (Wh) or kilowatthours (kWh).

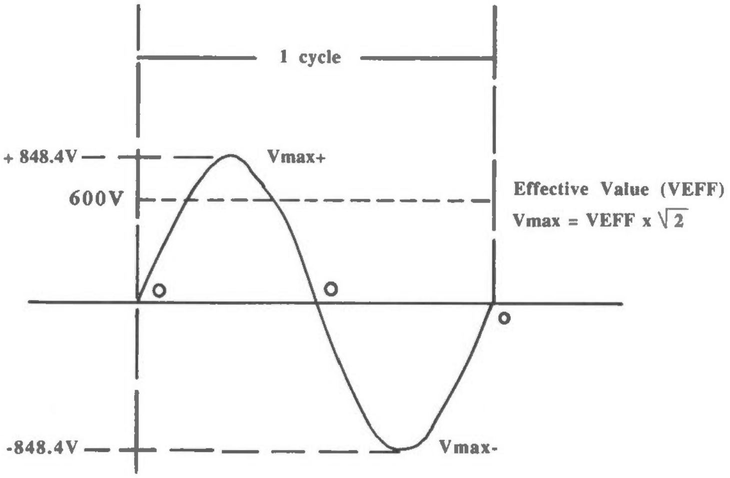
Energy = P x T = Watthours

Alternating Current (ac)

As the name implies, alternating current flows in one direction and then in an other; reversing its flow on a regular basis.

Electric utilities transmit alternating current electricity to their customers mainly because an alternating voltage can be easily raised and lowered. The voltage of electricity is raised before being transmitted across long distances (so as to reduce transmission losses) and then lowered when the electricity reaches distribution substations where it is distributed to homes, offices and plants, etc.

Alternating current voltage oscillates between zero and a maximum positive value (Vmax), back to zero, then to a maximum negative value before returning to zero where it begins a new cycle. In Canada, voltages complete 60 full cycles per second.



Alternating Current Wave

Figure 3

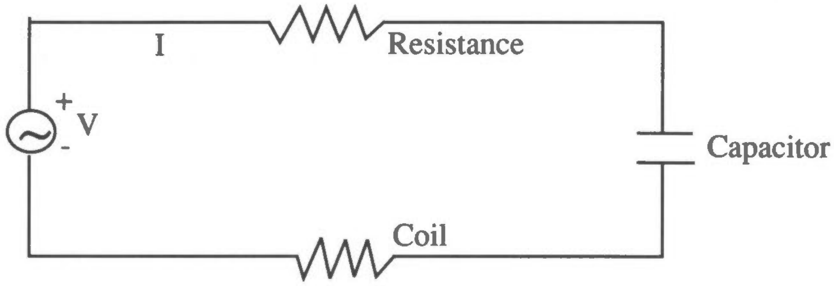
The effective value (Veff) or root mean square value $\sqrt{2}$ of the voltage shown on the curve (Figure 3) is equal to approximately 71 per cent of the maximum voltage. The same relationship holds true in the case of alternating currents. This effective value of voltage, times the effective value of the current, produces the same heating effect as in a dc circuit. Generally speaking, voltmeters and ammeters are calibrated to read the effective values of voltages and currents. Thus, in a building or a plant where the effective or nominal voltage is 600 volts, the maximum voltage is:

$600 \times \sqrt{2}$
$= 600 \times 1.414$
$= 848.4$ volts

The current flowing in an ac circuit (Figure 4) is equal to the voltage, divided by the total opposition to the flow, otherwise called impedance. This impedance represents the resistance of the wire as well as all other components, such as capacitors, coils and other devices, which may be part of the circuit.

Hence:
$I = V/Z$

where
I = Current (A)
V = Voltage (V)
Z = Impedance (Ω)



Typical ac Circuit
Figure 4

When an electric circuit contains only resistances, the maximum value of current occurs at the same instant as the maximum value of voltage. In practice, however, most circuits contain components which cause the current and voltage to be "out of phase". In such cases, the maximum value of current does not occur at the same instant. Only the current which is in phase with the voltage is capable of producing useful work. Therefore, the power in such a circuit is equal to:

$P: V \times I \times \text{p.f.}$

Where

P: power (W)
p.f.: power factor

(Power factor will be dealt with in the next section.)

When single phase lines do not have the capacity to carry the total amount of power required, three phase distribution systems are generally employed. Figure 5 shows the three sine waves produced by a conventional three phase generator. In such systems where the three phases are balanced, the power can be expressed by the formula:

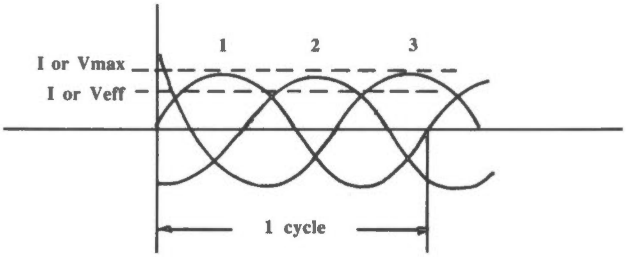
$P = V \times I \times \sqrt{2} \times \text{p.f.}$

where

P = power (W)
V = line voltage (V)
I = line current (A)
$\sqrt{2}$ = a constant relating currents and voltages in three phase systems.

For example, the power expended in a three phase, 600 volt system, where a line current of 20 ampere flows at 80 per cent p.f., is equal to:

$P = 600 \times 20 \times \sqrt{2} \times 0.8 = 16{,}627$ watts or 16.6 kW.



Sine Waves From Three-Phase Generator
Figure 5

Electricity Distribution

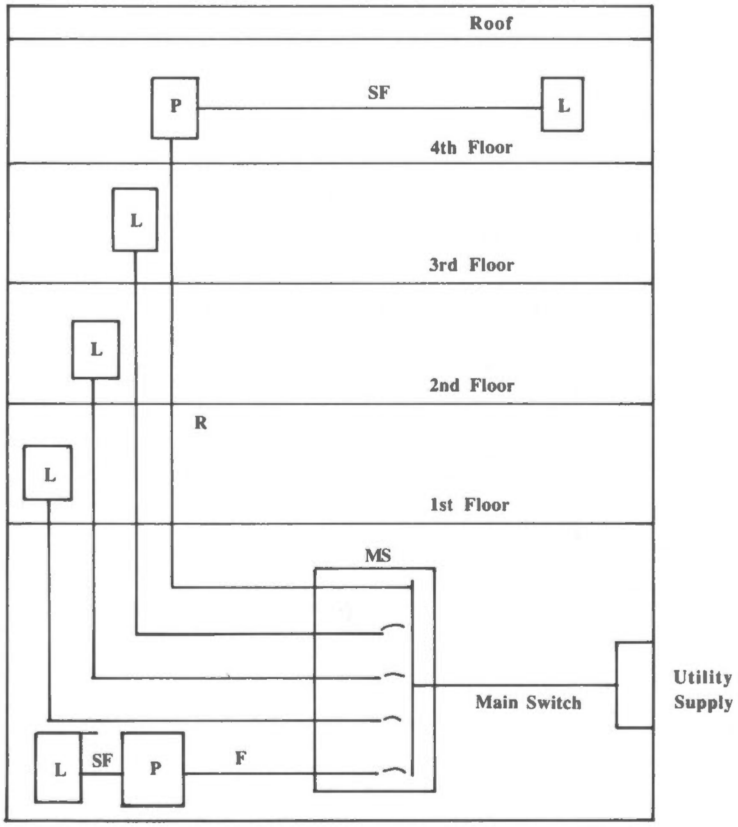
Electricity from the supplier's distribution system is normally delivered to a substation consisting of one or more transformers and auxiliary equipment such as switches and various protective devices.

At the substation, voltage is lowered to a level which can be used for a wide range of lower voltage applications. From the substation, electricity is distributed to homes, offices and buildings or plants which are connected to the local electrical distribution system.

Electricity enters a building or plant through a service entrance which contains switches, protective equipment and a panelboard or switchboard. This panelboard or switchboard distributes electricity to branch electrical circuits within a building. Each of these circuits should be protected by a properly-sized fuse or circuit breaker. It is through electrical conductors called feeders, that electricity eventually reaches various electrical devices. It is often more economical for some of these feeders to bring power to one or more auxiliary panelboards from which subfeeders can serve appropriate loads. Figure 6 represents a simple distribution system within a building.

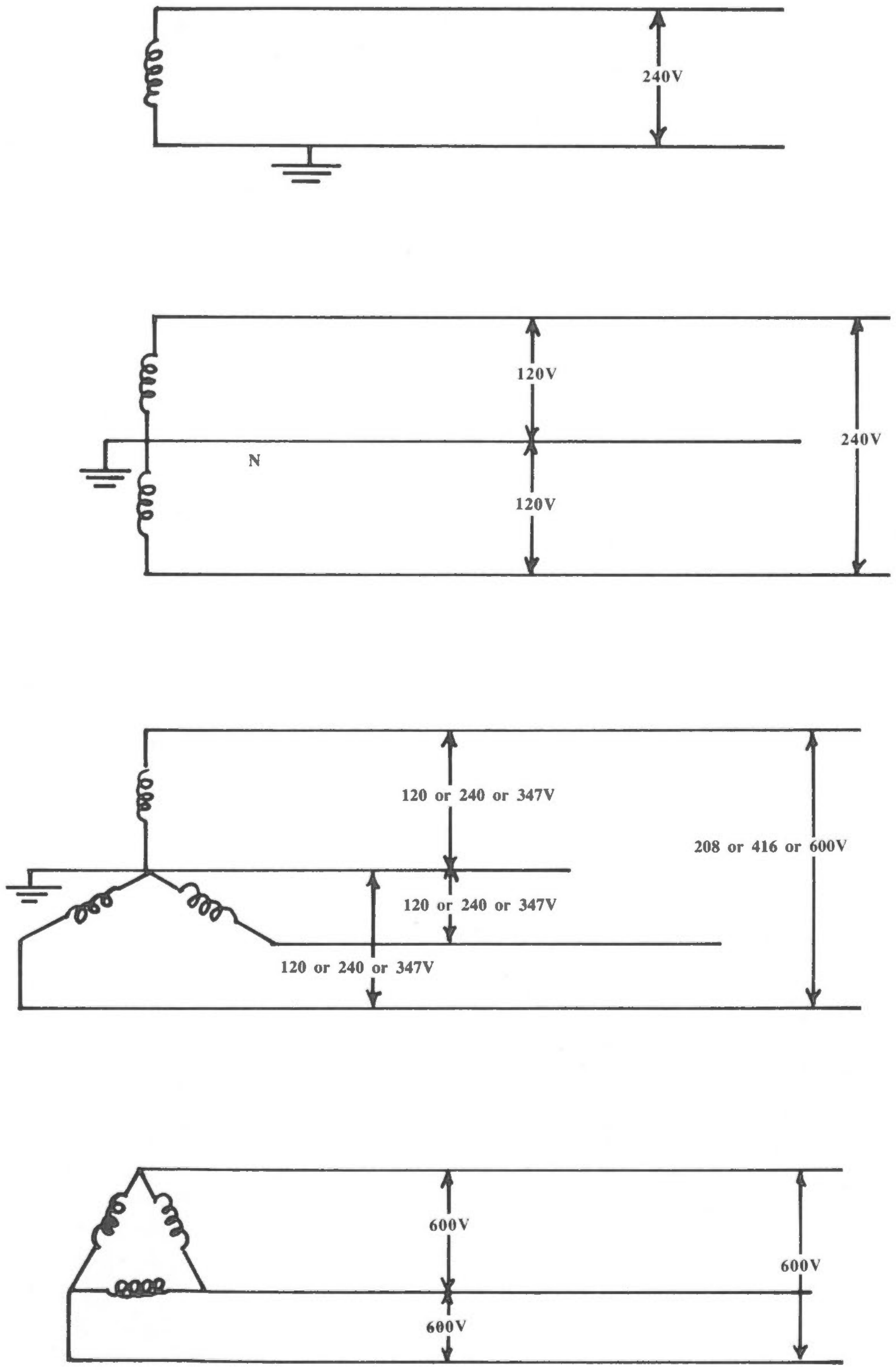
The more common utilization voltages used in Canada are illustrated in Figure 7. The terms wye and delta refer to the specific types of distribution arrangements.

Note: Large electricity consumers such as industrial plants and large buildings sometimes use higher voltages because of the magnitude of the electricity loads involved. In such cases, voltages such as 12 and 25 kilovolts (kV) are often used.



Legend
F=Feeder
L=Lighting Panel Board
MS=Main Switch Board
P=Power Panel Board
R=Riser

Typical Electrical System Distribution Layout
Figure 6



Single-Phase

IWO Wire 240 Volts

Single-Phase

Three Wire
120/240 Volt

Three-Phase

Four Wire

120/208 Volts Wye
240/416 Volts Wye
347/600 Volts Wye

Three Phase

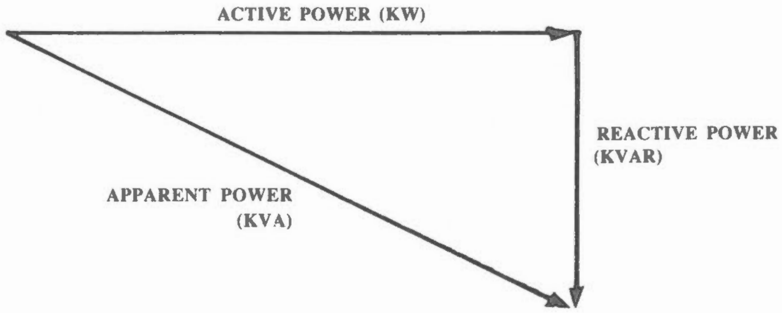
Three Wire
600 Volts Delta

Common Utilization Voltages
Figure 7

Power Factor (p.f.)

As mentioned earlier, voltage and current in ac circuits are often "out of phase". Power factor is a means of expressing how much of the current flowing in a circuit is "in phase" with the voltage. As demonstrated earlier, only current which is in phase with voltage is capable of doing useful work.

Power factor can best be represented in the power triangle shown in Figure 8.



Typical Power Triangle
Figure 8

Electricity delivered by an ac circuit consists of two components: "active power", which is the component capable of doing work, measured in kilowatts (kW); and "reactive power", which is measured in kilovolt-amperes reactive (kvar) which does no work, but is necessary for electrical machinery to function. The combination of both active and reactive power has been named "apparent power". This is measured in kilovolt-amperes or kVA and is the total power which must be supplied to the end user. The ratio of kilowatts to kilovolt-amperes is known as "power factor". Power factor is expressed as a fraction and cannot be greater than one.

$$\text{p.f.} = \frac{\text{kW}}{\text{kVA}}$$

For instance, a circuit carrying 30 kilowatts, with an apparent power of 40 kilovolt-amperes, has a power factor of:

power factor (p.f.)
= 30 ÷ 40
= 0.75
or
= 75%

The electrical utility measures both kW and kVA and will usually bill the customer on the basis of power factor.

Most utilities impose a penalty for a power factor of less than 90 per cent. This penalty is like the demand charge in that it is related to the increase in the generating capacity required by the utility. It is important to remember that, in addition, all of the electricity supplied will contribute to heating effects and must be taken into account when sizing transformers, conductors and generating equipment.

For these reasons, it is generally a good economical practice to correct low power factor loads. Electric induction motors, induction and arc furnaces, welders, transformers and low quality fluorescent lighting fixtures are the most common "low-power-factor" loads.

Correction

Reducing the reactive portion of power in a circuit also reduces apparent power. Since there is usually no change in active power, power factor will improve as reactive power is reduced. A power factor of "unity" (1.0) or 100 per cent, indicates that reactive power has been completely corrected and that active power is now equal to total apparent power.

Capacitors can be used to correct that portion of the out-of-phase current that contributes to reactive power, thereby reducing or correcting power factor.

Power factor can be corrected on individual feeders near the service entrance or near the location of low-power-factor loads.

A larger capacitor, located near the service entrance, is lower in initial cost than individual capacitors required to correct the power factor of each feeder. This, however, will not relieve overloaded feeders on the load side of the capacitor. In addition, switching devices may be required to control the amount of correction used when the system is only partially loaded.

Installing capacitors on grouped equipment can also be cheaper than individual correction techniques. This will improve the load capabilities of the electrical service but may require switching to control the amount of correction as the system load varies.

Individual power factor correction is normally preferred because it is usually economical for 10 hp units and up. This method of installing capacitors on equipment will permit increased load capabilities on the distribution system and will help to maintain a more constant voltage. This is because capacitor use follows the load. These capacitors can be switched on with the equipment and can be moved with the equipment, should changes in plant layout occur.

Sample calculation

An electrical utility customer wishes to improve the power factor of his electrical installation which has the following characteristics:

Meter readings:	active power = 160 kW apparent power = 200 kVA

Meter multiplier: 100
Actual consumption is the meter reading x meter multiplier

thus:

160 kW x 100 = 16,000 kW
and
200 kVA x 100 = 20,000 kVA

Power factor is then calculated the following way:

= kw ÷ kVA
= 16,000 ÷ 20,000
= .80 p.f.

Electricity rates are normally based on the maximum value of two quantities: either maximum demand (measured in kW) or maximum demand measured in kVA at 90 per cent power factor. On this basis, a customer who has 80 per cent power factor can expect to be billed for 16,000 kW or 20,000 kVA at 90 per cent power factor.

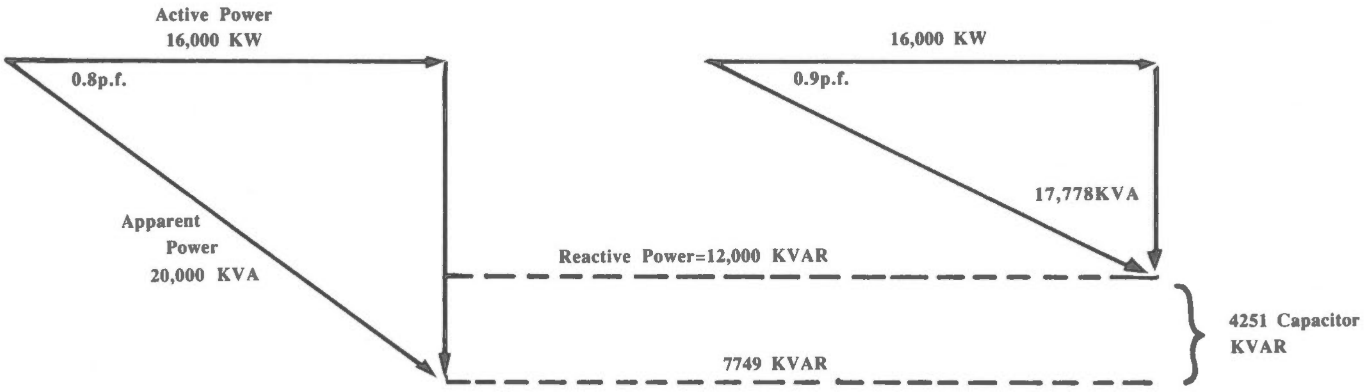
It just so happens that 20,000 kVA at 90 per cent power factor is equivalent to 18,000 kW. This being the case, the customer could expect to pay for an additional 2,000 kW of electricity, at whatever rate per kilowatt the local electricity charges.

In order to avoid a power factor penalty, the electricity consumer should determine the minimum capacitor size that would be required to correct his power factor from 80 per cent to 90 per cent.

Two power triangles, shown in Figure 9, are used to demonstrate the amount of corrective reactive power required to increase power factor.

Since active power remains the same, the corrected apparent power component can be determined for a 90 per cent power factor in the following way:

Power factor = kW ÷ kVA
Solving for kVA:
kVA = 16,000 ÷ .9
= 17,778



Power Factor Correction

Figure 9

Using simple algebra, the reactive power can be calculated for both cases:

At 0.8 p.f.
Reactive power $= \sqrt{(20{,}000)^2 - (16{,}000)^2}$
$= 12{,}000$ kvar

At 0.9 p.f.
Reactive power $= \sqrt{(17{,}778)^2 - (16{,}000)^2}$
$= 7{,}749$ kvar

The capacitor to be selected must correct the reactive power by:

12,000 — 7,749
= 4,251 kvar

Table 1 indicates kW multipliers which can be used for determining the capacitor kilovars required for power factor improvement.

Using Table 1, the multiplier required to improve power factor from 0.8 to .09 is 0.266,

hence:
16,000 x 0.266
= 4,256 kvar

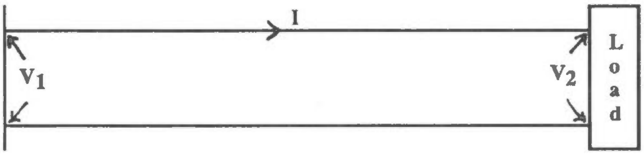
Comparing this value (4,256 kvar) determined by Table 1, to the value obtained by detailed calculation (4,251 kvar), demonstrates that the use of such tables gives a reasonably close approximation.

Manufacturers' and suppliers' catalogues provide for the required capacitor to be selected according to the number of kvar it can supply.

Economic parameters often favour correcting power factor beyond this minimum value. This example is further developed in the Energy Management Opportunity section of this module.

Voltage Drop

Voltage drop (Figure 10) occurs in all electrical circuits and is easily demonstrated as the difference in voltage between the load terminals and the service entrance.



Typical Voltage Drop
Figure 10

Voltage drop is also called the IR drop because it is equal to the resistance of the conductor, multiplied by the current flowing through the conductor.

V drop = $V_1 — V_2 = I \times R$

Where
V drop = voltage drop within conductors (V)
I = current (A)
R = resistance (Ω)

Excessive voltage drop in conductors is not only a source of energy loss but it also has adverse effects on electrical equipment. For instance, incandescent lamp output drops at a faster rate than the voltage. This results in a lower operating efficiency. Also, fluorescent lamps may experience starting difficulties and ballast overheating as a result of excessive voltage drop. Voltage drop in motors can lead to overheating and starting problems.

When diagnosing operating problems in electrical equipment, voltage drop should be considered. While the Canadian Electrical Code recommends voltage drops of five per cent or less to be incorporated in new feeders and sub-feeders, unplanned loads are often added to existing equipment. These new loads increase current and therefore voltage drop in existing wiring facilities. This often occurs to the point where the only solution is to add new feeders or to replace existing feeders with larger ones.

Voltage drop can be assessed while carrying out diagnostic activities by taking readings at the service entrance and at load terminals.

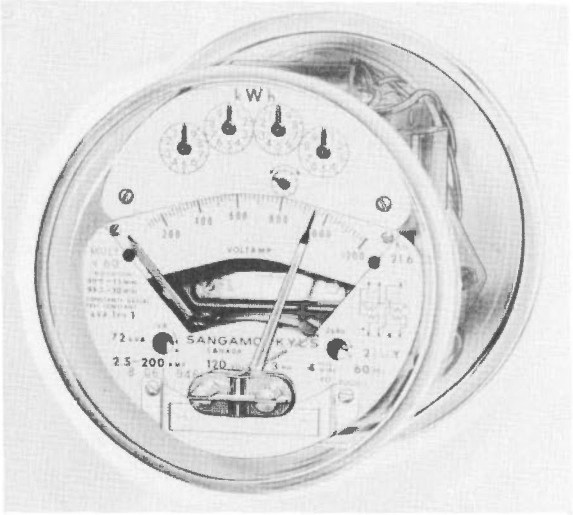
Metering and Rates

Meters are essential for determining how and where electricity consumption can be reduced. But a few basic questions must first be answered.

1. What is the electricity consumption of the building or facility?
2. When and where is the electricity being consumed?
3. How much am I paying for it?

Figure 11 shows a typical electricity demand meter. These are used for most commercial and small industrial businesses. To calculate electrical consumption and therefore cost, it is necessary to read and record the readings from a demand meter and a "demand register".

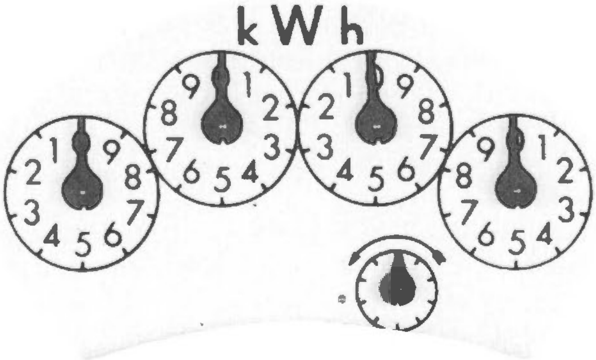
With these figures and a copy of the electricity bill, the user can accurately calculate his monthly cost by applying the proper rate structure. The demand meter is capable of measuring both electricity consumption and electrical demand.



Energy And Demand Meter
Figure 11

Energy Consumption

Energy consumption is the total amount of electricity consumed and is measured in kilowatthours (kWh). By reading the energy dials at the top of the meter, one can determine how much energy (kWh) has been consumed. Figure 12 shows a close up of such dials. In this case, there are four dials. Large energy users may have five or more dials on their meters.



Energy Meter Dials
Figure 12

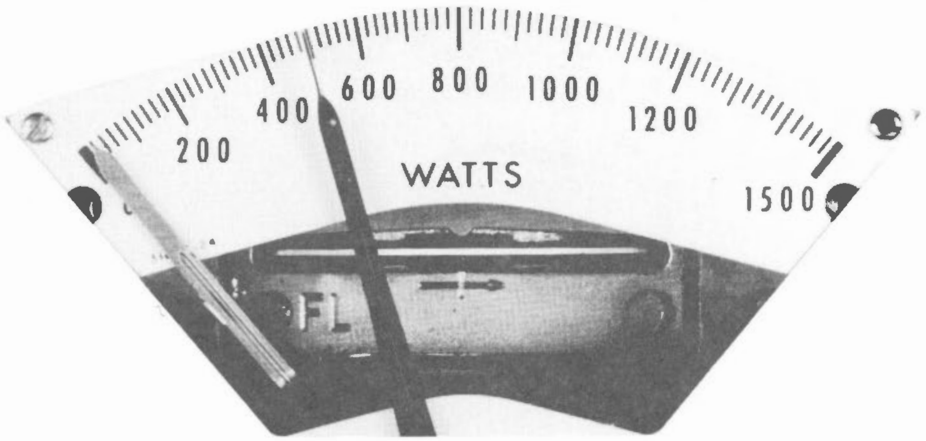
Demand

"Demand" is the rate at which electricity is delivered to a load and is usually expressed in either kilowatts (kW) or kilovolt-amperes (kVA). "Maximum demand" refers to the maximum rate at which power is consumed during a billing period. "Billed demand" is the maximum consumption rate considered by a utility for billing purposes. It can be the monthly maximum kW or KVA demand or some kWor KVA demand based on previous monthly maximum demands.

When a customer requires a large supply of electricity, even for a short period of time, the local utility's electrical supply system must be designed to accommodate this requirement.

Most commercial and industrial businesses are charged for demand as well as for electricity consumption. For example, assume that a customer operates a 2 kW space heater, a 4.5 kW water heater and a 10 kW oven — all at the same time. The electrical demand created would be 2 + 4.5 + 10 = 16.5 kW. Even if the oven only operated for one hour per day, the user's demand bill for the month will be based on the total amount, which is 16.5 kW.

Figure 13 shows a typical electrical demand scale. It has two pointers, one red and one black. The red pointer measures actual demand. The speed at which the red pointer reacts to a steady load varies with the time interval which is built into the meter. Most utilities utilize a fifteen minute interval. The black pointer indicates the maximum demand during the billing period. When the red pointer advances, it drives the black pointer forward at the same rate. However, when the red pointer retreats, the black pointer remains stationary, indicating the maximum demand.



Demand Scale
Figure 13

The black pointer is manually reset back to the red pointer after the meter reading is recorded. This procedure is repeated during each meter reading.

When reading an indicating-type meter, care must be taken to avoid errors due to a phenomenon known as "parallax". The pointer position must be read from directly in front of the meter. If it is read from one side or the other, the value will be increased or decreased accordingly. Also, care must be taken to read the proper scale subdivision.

The Meter Multiplier

Actual voltages and currents used in many applications are often too large to be registered by a meter. To solve this, a "meter multiplier" can be used. This type of meter is similar to a scaled map, in that it relates actual consumption to a scaled down reading. This type of meter has both an internal and an external multiplier. The product of these two multipliers provides the overall meter multiplier.

The internal multiplier (Figure 11), and the external multiplier is the result of the actual versus maximum current and voltage scale readings of the meter.

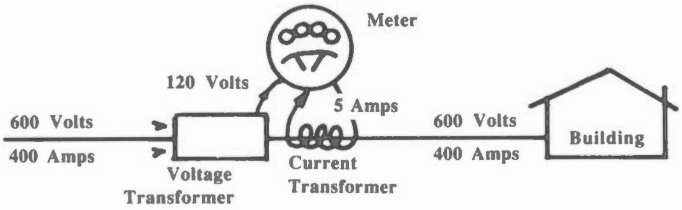
If, for example, 600 V and 400 A are required by a customer and the maximum capacity of the meter is 120 V and 5 A, as shown on the meter scale in Figure 14, the external multiplier would be:

600 ÷120 = 5 = the voltage multiplier
400 ÷ 5 = 80 = the current multiplier
5 x 80 = 400 = external multiplier

In this example, the internal multiplier as indicated on the face of the meter is 2. Thus, the overall multiplier would be:

2 x 400 = 800

The overall multiplier is usually indicated on the power bill and can be verified using the above calculation.



Multipliers
Figure 14

Electricity Rates — General Considerations

Electricity rate structures determine how electrical utilities charge their customers for different units of electricity consumed.

Rates vary from utility to utility and are usually modified quite frequently. Along with ratebooks, they do not have the reputation for being "user friendly". While it is important to manage loads properly and efficiently, understanding utility rates which apply to a particular type of operation is necessary if load management measures are to be effective. Rate options may be available but they will not generally be incorporated into billing procedures unless requested by the customer.

Rates specify, among other things, how electricity consumption (kWh) and electricity demand (kW) will be billed. Whereas most customers are billed on the basis of electricity consumption and demand, very low consumption customers are sometimes billed on the basis of consumption only. For this reason, commercial, institutional and industrial rates are generally divided into small, medium and large power categories.

Rate Structures

Rate structures can be of the single block or multiple block type. With single block rates, both electricity consumption and demand are billed at a single rate. They are often called "postage stamp" rates.

For example, a customer consumes 200,000 kWh during one month and the peak demand is calculated at 700 kW. The utility rate is a single block rate at $5.00 per kW per month and the electricity consumption is billed at $0.04 per kWh. The power bill for the month will be:

700 kW x $5.00/kW = $3,500
200,000 kWh x $0.04/kWh = $8,000
Total = $11,500

Some utilities also include a fixed customer monthly charge to the electricity bill or specify a minimum monthly bill.

In the case of multiple block rates, which are more common, the electricity consumed is separated into blocks which are billed at different rates.

For example, using the previous example and applying the following multiple block rate: the power bill for the month could be calculated:

Block rate: $5.00 per kW/month of billing demand
First 10,000 kWh at $0.08 per kWh
Second 50,000 kWh at $0.05 per kWh
Remainder at $0.03 per kWh

Note that the billing demand, mentioned above, can be:

1. the peak monthly demand in kW;
2. the peak monthly kVA demand at a certain power factor (usually 0.9 or greater);
3. a peak demand of previous months; or
4. a minimum demand as specified in the power contract.

Assuming that the peak monthly kW demand applies, the electricity bill for the month will be:

Electricity demand: 700 kW x \$5.00/kW = \$3,500
Electricity consumption:
10,000 kWh x \$0.08/kWh = \$800
50,000 kWh x \$0.05/kWh = \$2,500
Remainder
200,000 — 60,000 = 140,000
140,000 kWh x \$0.03/kWh = \$4,200
Total = \$11,000

Multiple block rates often tie in a demand component. In this type of rate, also known as variable block rates, the amount billed in each block depends on the overall consumption and on the billing demand for the period.

For example, consider the previous example and apply a variable block rate:

Consumption: 200,000 kWh/month
Peak demand: 700 kW

Rate:
\$5.00 per month per kW of billing demand
\$0.06 per kWh for the first 120 hours of the billing demand kilowatts
\$0.04 per kWh for the next 70,000 kWh
\$0.03 per kWh for the remainder of the consumption

The power bill in this case will be:

Electricity demand: 700 kW x \$5.00/kW = \$3,500

Electricity consumption: 120 hrs x 700 kW = 84,000
84,000 kWh x \$0.06/kWh = \$5,040
70,000 kWh x \$0.04/kWh = \$2,800
Remainder: 200,000 — 154,000 = 46,000
46,000 kWh x \$0.03/kWh = \$1,380
Total = \$12,720

The rate structures used in these calculations are for illustrative purposes only. Ultimate user costs will depend on electricity consumption, demand and the load factor of a particular installation.

Utilities include a number of different features in their rate structures. One such feature is the power factor clause which specifies that the billing demand will be greater than the actual demand in kW, or the kVA at a certain power factor, usually 90 per cent or greater. If the power factor is therefore significantly lower than 90 per cent, a substantial cost penalty can be incurred.

Another aspect of utility billing techniques is the "ratchet" or "minimum demand" clause. This clause usually specifies that the monthly billing demand shall not be less than the actual measured monthly demand in kW or a percentage of the highest monthly demand during a given period (often the previous eleven months). This can have a serious impact on the final bill, since the customer's rate is based on the peak demand from a single occurrence during a given time period. Some utilities also have seasonal rates, during which the ratchet may or may not apply, depending on whether the season is a peak or off-peak period. A winter-peaking utility may, for instance, sometimes drop the ratchet during the summer months.

Analyzing Electricity Bills

In analyzing electric utility bills, one must determine the following for each meter location:

- the rate applied and other conditions of service;
- the rate options available for this kind of service, if any;
- the manner in which the rate structure is applied when calculating the billing demand;
- power factor clauses, if any;
- fuel adjustment clauses, if any, where the utility is generating with fossil fuels; and
- other factors such as present and future service voltages.

Upon request, utilities will make representatives available to explain their rate-making policies.

Utility/In-House Meters

Electric utilities generally supply one metering point per rate. In some medium or large power installations, this single metering point may not supply enough information. In this case, the installation of in-house meters should be considered. This would normally follow a preliminary audit to indicate the need for additional data. This data will permit a closer examination of each major component for: input or output power, power losses and power factor correction.

Demand Management and Control

An effective demand management and control system should take into consideration elements such as: daily load profile, load factor, load shifting, and load shedding.

Daily Load Profile

A daily load profile of an electrical installation should be drawn in order to determine at what time during a typical day maximum demand occurs, what contributes to this maximum demand, and where savings can be made. A sample profile is shown in Figure 15. This figure graphically illustrates the energy demand during a 24-hour period. Electricity demand data can be obtained by reading at various times of the day the pointer on the demand scale.

Load Factor

Load factor is defined as the percentage of time during which peak demand is utilized. This is measured over a given period, whether it be a day, month, or year. Load factor is a measure of the effectiveness with which electricity demand is managed.

For example, an electrical load which created a 100 kW demand and consumed 1200 kWh during a day has a daily load factor of:

$$\text{Per cent load factor} = \frac{\text{kWh}}{\text{KW x hrs}} \times 100$$

$$= \frac{1200}{100 \times 24} \times 100$$

$$= 50\%$$

As a general rule, electricity rates are structured in such a way that a higher load factor will result in a lower average cost per kilowatt-hour.

Load Shifting and Load Shedding

Some essential loads which must operate on a priority basis, such as production equipment, can sometimes be shifted by carefully reprogramming production schedules.

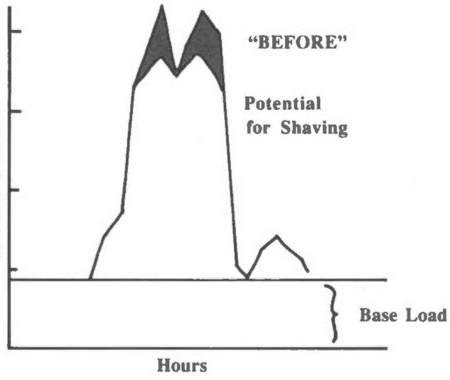
In other cases, non essential loads that must be energized for a certain amount of time every day are shed at peak times and re-energized during off-peak periods. Typical non-essential loads are water heaters, large motors such as those used with grinders, electric boiler operations, chillers, de-icers, snow melters and some types of ovens and tank heaters.

Example of Load Shifting

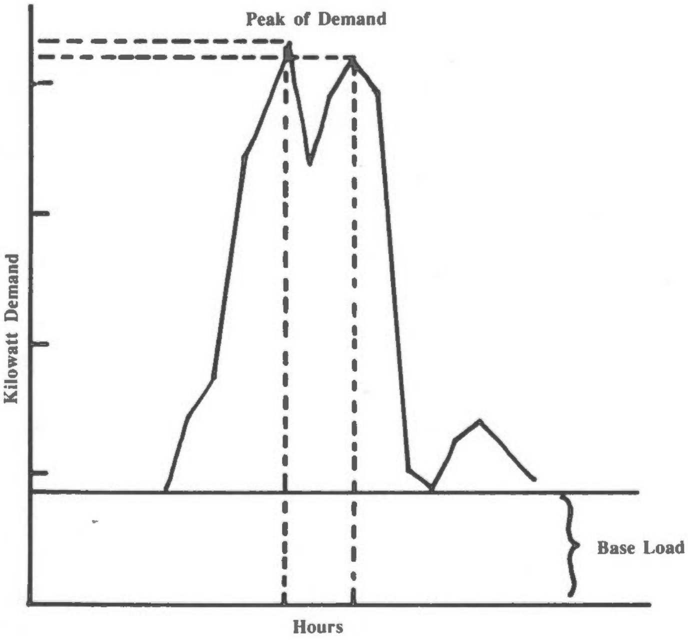
As mentioned earlier, Figure 15 illustrates a typical daily load profile which includes a base load. Base load includes all equipment, such as heating, ventilation, security lights, etc, which operates on a continuous basis.

Figure 15 demonstrates that electrical equipment begins operating at 06:00 hrs. Equipment continues to be turned on until a peak load is reached at 11:00 hrs. This peak falls off significantly at 12:00 hrs, during lunch hour. After lunch, equipment is turned on again and a second peak is reached at 14:00 hrs. At 16:00 hrs, likely closing time, there is a significant reduction in electricity demand.

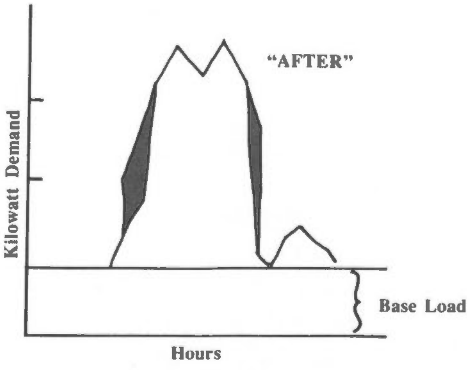
Figure 16 shows how savings can be achieved by shaving these peaks. Load shaving is a technique used to shift a portion of the electrical load at a peak time of the day to a non-peak time. Total consumption, however, is not reduced. For example, instead of having 12 machines operating at 11:00 hrs, three machines could operate at 13:00 hrs, six machines at 11:00 hrs, and three machines at 13:00 hrs. All 12 machines would still operate during the course of the day but not all at the same time. Figure 17 demonstrates the daily load profile after the peaks have been shaved. It can be seen that the solid area in Figure 16 is equal to the solid area in Figure 17. The electrical consumption, however, has been shifted in time and the area it represents relocated. This effort reduces overall peak demand while at the same time producing a higher load factor.



Peak Shaving (Before)
Figure 16



Typical Load Profile
Figure 15



Peak Shaving (After)
Figure 17

Example of Savings

To best illustrate the importance of electricity demand management from a cost standpoint, consider the case of two companies who both utilize the same amount of energy, except that one company creates a lower monthly demand than the other. The monthly billing rate for both companies is as follows:

Variable block rate:
(Demand) • $4.00 per kW of billing demand
(Consumption) • $0.05 per kWh of the first 120 hours of use of the billing demand
• $0.035 per kWh for the next 78,000 kWh
• $0.025 per kWh for the remainder of the consumption
In the following example, the billing demand is equal to the peak monthly demand in kW.

Billing demand, customer A : 200 kW
Billing demand, customer B : 300 kW
Energy consumption : 90,000 kWh in each plant

Monthly bill for customer A:

Demand charge:	
200 kW/mo x $4.00/kW:	$ 800.00
Energy consumption charge:	
First block:	
200 kW x 120 hrs : 24,000 kWh x $0.05/kWh:	$1,200.00
Second block:	
90,000 kWh - 240,000 kWh:	
66,000 kWh x $0.035/kWh:	$2310.00
Total:	$4,310.00

Monthly bill for customer B:

Demand charge:	
300 kW/mo x $4.00/kW:	$1,200.00
Energy consumption charge:	
First block:	
300 kW x 120 hrs : 36,000 kWh x $0.05/kWh:	$1,800.00
Second block:	
90,000 kWh - 36,000 kWh:	
54000 kWh x $0.035:	$1890.00
Total:	$4,890.00

Difference in power bills:
$4,890.00 — $4,310.00 = $580.00/month

Average energy cost to customer A:

$$\frac{\text{Cost}}{\text{kWh}} = \frac{\$4310.}{90{,}000} = \$0.0479/\text{kWh}$$

Average energy cost to customer B:

$$\frac{\text{Cost}}{\text{kWh}} = \frac{\$4890.}{90{,}000} = \$0.0543/\text{kWh}$$

Average monthly load factor — Customer A:

$$\frac{\text{kWh}}{\text{kWh x hrs}} \text{ x } 100 = \frac{90000}{720 \text{ x } 200} \text{ x } 100 = 62.5\%$$

Customer B:

$$\frac{90000}{720 \text{ x } 300} \text{ x } 100 = 41.7\%$$

Customer A, with a lower monthly peak demand, pays $580.00 less a month for his electric energy. His average cost per kWh is:

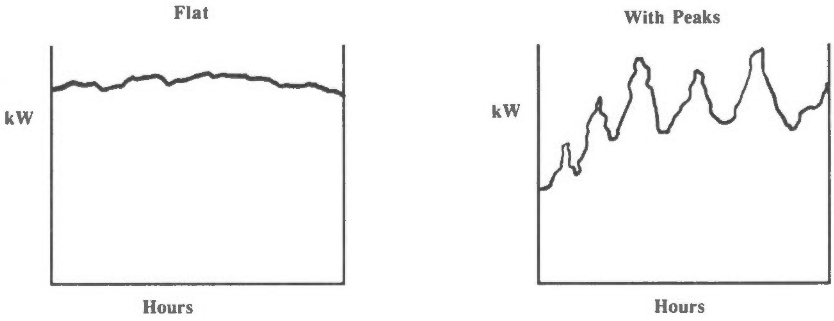
$$\frac{\$0.0543 - \$0.0479}{\$0.0479} \text{ x } 100 = 13.4\% \text{ lower}$$

Load Profile Analysis

An analysis of a demand load profile curve for an electrical installation can help identify peak demand reduction opportunities.

It can be easily seen from Figure 18 that a smooth, flat, high load factor demand profile requires less peak demand control than a profile with load spikes.

The analysis of a demand profile will reveal the nature and operating patterns of connected electrical equipment.



Typical Load Profiles
Figure 18

When it is impossible to shift a few selected loads from one operating time to another, the installation of automatic demand shedding controls may be the best alternative. The advisability of such a measure will depend on the nature of the load profile and of its components (essential versus non essential loads) .

The strategy for demand load shedding must be determined carefully to avoid operating problems. In most cases, such a strategy can be manually tested on a small scale before a commitment is made to install relatively expensive demand control devices. For example, fans can be manually turned off for selected periods in order to insure that building temperatures remain at acceptable levels before installing control equipment to regulate the operation of such fans.

Thermal storage

One energy management option is the technique of thermal storage. Storing thermal energy for use at a later time can help to cope with energy demand peaks, while at the same time justifying the development of waste heat recovery and alternate energy source projects.

The decision to make use of thermal storage devices depends largely on the economics of reducing electrical peaks and/or using electrical power during off-peak periods. It is here that an electric utility's rate structure plays an important role in determining the economic feasibility of such a thermal storage system. The total consumption of energy for a particular application will be greater with the use of a thermal storage system, due to the additional heat losses inherent in the storage process. However, the reduced peak demand which contributes to the lower cost of electricity during off-peak periods can, in may cases, more than compensate for the additional energy consumption.

Those interested in pursuing this topic should refer to Module #19, (Thermal Storage) in this series.

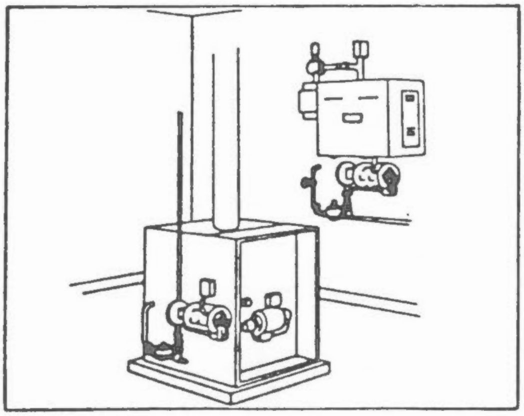
Dual-Energy Systems

Another method of shaving electrical peaks consists of installing stand-by, fossil fuel-fired energy systems. These systems (Figure 19) operate during specific periods (ie, extremely cold days) when electrical loads reach predetermined peaks. Several Canadian electrical utilities often find it worthwhile to shave the first few hundred hours from their system peaks and will offer compensatory rates to those customers who cooperate in reaching this objective.

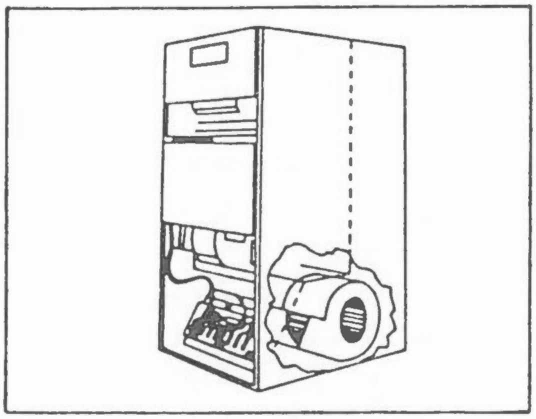
An analysis of a building's or plant's total energy picture will indicate whether this dual-energy option is economically viable. This examination should include an analysis of competitive rates from all energy suppliers, since many electric and gas utilities offer interruptible rates of which can be taken advantage. Petroleum retailers also offer bulk rates which can be combined with adequate storage facilities.

The use of dual-energy systems and interruptible electricity rates will depend on:

— relative cost of the different energy sources;
— length of supply contracts which can be secured;
— capital cost of additional equipment required; and
— utility incentives.



Oil or gas-electric forced air
A self-contained combination system



Oil or gas fired boiler system
Electric boiler option

Dual Energy Systems

Figure 19

Transformers

Details of transformer operation or design will not be addressed in this text because of their inherent complexity but in simplified terms, a transformer is used to change the voltage or current of an ac electrical circuit, or to occasionally isolate two electrical circuits while they are still interchanging energy. A transformer essentially consists of a core, around which are wound primary and secondary windings (Figure 20). Variations in the primary voltage induce electro-motive forces in the secondary windings and hence energize this winding.

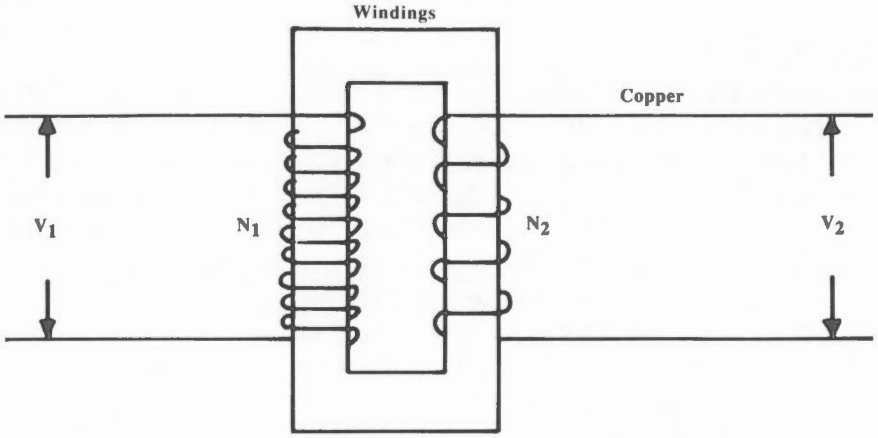
The efficiency of a transformer can be expressed in the following relationship:

$$\text{Efficiency: } \frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{\text{Output + Losses}}$$

$$\text{\% Efficiency: } \frac{\text{Output}}{\text{Input}} \times 100$$

Transformer losses are due to the following factors:

1 - Primary copper loss: $I^2 R_1$
2 - Secondary copper loss: $I^2 R_2$
3 - Core loss made up of:
  a) Hysteresis loss and;
  b) Eddy-current loss.



N_1 = No. of Turns in Primary Windings
N_2 = No. of Turns in Secondary Windings
V_1 = Primary Voltage
V_2 = Secondary Voltage

Basic Transformer
Figure 20

Well-designed transformers have operating efficiencies greater than 90 per cent. These transformers have windings which minimize I^2R losses through the use of low-resistance conductors. Their cores, made up of materials which are easily magnetized and demagnetized, produce lower hysteresis losses. Eddy currents are minimized through the use of laminated transformer cores, made out of thin sheets which offer high resistance to eddy current flow.

Loading

Transformer efficiency calculations require an estimation of the percentage at which the transformer is utilized, or the "loading percentage".

Transformer nameplates specify full load ratings. Ratings are rated in kVA, based on a given terminal voltage and frequency. The loading percentage is normally expressed in terms of the transformer's full load rating.

For a plant or building extension, the data can be collected from transformer sizing calculations. Loads to be served from a new transformer and scheduled to operate simultaneously with an existing transformer are added to determine the size of the new transformer. This information (kW output) can be used in calculating savings through improved transformer efficiency.

For existing installations, the daily kW load profile should indicate the transformer loading if a single transformer is utilized. When more than one transformer is used, volt-ampere readings can be used to determine loading percentage. For single-phase, three-wire installations, these measurements might indicate the need to rebalance the two circuits. That is, to distribute loads more evenly between the two transformers. Similarly, three-phase transformers require that electricity in each phase be measured and added to indicate the total loading. This is also an occasion to make certain the phases are in balance. That is, that they carry approximately the same share of the total load. Measurements must be taken when the transformer is supplying maximum loads in the course of normal operations.

Some transformers are connected to panelboards or switchboards that contain the necessary meters to determine transformer loading. It is also possible, in some circumstances, to read the kilovolt amperes and kilowatts on the utility's meters before and after the transformer is energized. The difference in the readings can also be used to calculate the transformer loading.

If the load profile varies substantially during a 24 hour period, and if more than one transformer is utilized, it might be advantageous to distribute the load so that one transformer handles all the loads during periods when only non-operational facilities (such as emergency lighting, security and fire systems, limited HVAC) are energized. The second transformer can be used to meet operational loads. This will reduce transformer losses and electricity consumption.

Savings

The cost savings achieved by the use of energy efficient transformers can first be calculated by determining the transformer output (kW). The output of a transformer depends upon the loads that it is called upon to serve. These loads are generally expressed as a percentage of the transformer's full load capability.

kW output = full load output x % loading

Secondly, a transformer efficiency formula can be used to compare the savings of an energy efficient (ee) transformer, as compared to a standard (std) unit:

Difference in kW input between std and e.e. =

$$\text{kW output} \left\{ \frac{1}{\text{std. efficiency}} - \frac{1}{\text{e.e. efficiency}} \right\}$$

In addition, hourly usage per year and the average cost per kWh can yield the following savings:

$ savings/yr = kW savings x hours/year x $/kWh

When a transformer has to be replaced, it is advisable to investigate purchasing an energy efficient model compared to a standard efficiency design. Generally speaking, transformers should be sized to operate at high load factors to ensure short pay-back periods on a premium cost basis as illustrated in the following example.

For example, a substation transformer, which in this case belongs to the customer, needs to be replaced.

The rating of the transformer required for present and estimated future needs is 500 kVA.

Estimated loading: 75%
Power factor: 90%
Estimated operating hours/year: 4,000 hrs
Manufacturer's data:
Efficiency of standard transformer: 91%
Efficiency of energy efficient transformer: 96%
Premium cost differential: $5,000
Billing data:
Average cost of electricity: $0.06 per kWh

kW output: rating x p.f. x % loading
kW output: 500 x .90 x 0.75
= 337.50 kW

$$\text{Dif. kW input} = 337.50 \left(\frac{1}{0.91} - \frac{1}{0.96} \right)$$

= 19.338 kW

$ savings:

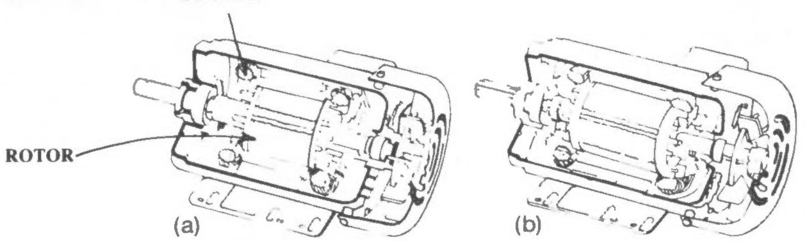
Dif. kW input x operating hrs/yr x energy cost/kwh
19.338 x 4000 x 0.06 = $4641. per year

$$\text{Simple payback} = \frac{\$5000}{\$4641}$$

= 1.08 years

Motors

Electric motors (Figure 21) are devices that convert electrical energy into mechanical energy. This is accomplished through the interaction between current-carrying conductors and magnetic fields. An electrical current from an external source creates an electromotive force which causes the rotor to turn, thereby producing mechanical shaft power.



Construction of (a) Standard and (b)Energy Efficient AC Motor Notice longer rotor/stator cores of the high efficiency motor.

Comparison of Standard and Energy-Efficient Motors

Figure 21

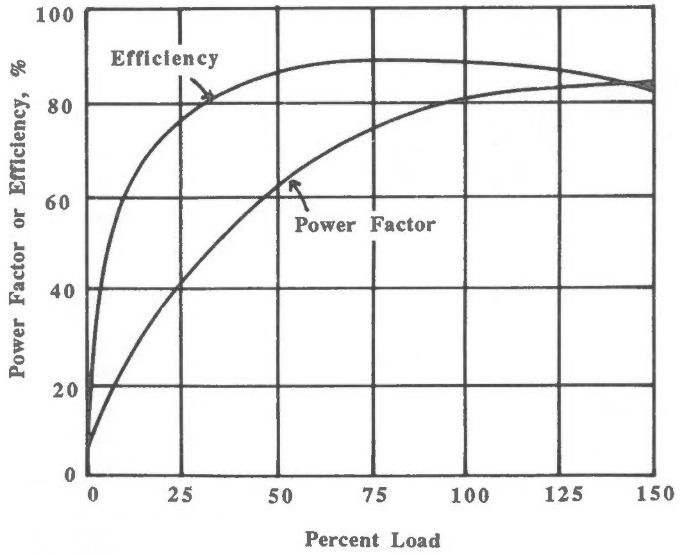
Electrical losses in motors include:

- stator and rotor copper losses;
- stator and rotor core losses; and
- friction and winding losses.

Motor efficiency can be expressed by the following equation:

$$\text{Efficiency} = \frac{\text{OUTPUT}}{\text{INPUT}} = \frac{\text{OUTPUT}}{\text{OUTPUT} + \text{LOSSES}}$$

Figure 22 shows a typical motor efficiency curve. It can be seen from this chart that motor efficiency increases from poor efficiency at light loads to near maximum efficiency when a motor reaches approximately 75 per cent full load. Power factor, discussed earlier, also improves as load increases. It is generally true that the larger the motor, the higher the motor efficiency. For example, the typical "full load efficiency" of a 1 hp motor is 70 per cent, while the full load efficiency of a 100 hp motor is 92 per cent.



Efficiency And Power Factor of Typical Three-Phase Motor

Figure 22

Loading

In order to determine motor efficiency, an estimation of the percentage of motor loading is required. This is the percentage of full load at which the motor operates.

Instruments discussed in the equipment section of this module can measure both line current and line voltage. These readings, along with motor data supplied by the motor manufacturer, are used to determine percentage loading. It is also possible, in some cases, to read kilovolt amperes (kVA) and kilowatts (kW) on an electrical utility's meters before and after a motor is energized. The differences in the readings can be used to calculate the motor loading.

Efficiency

About 50 per cent of Canada's total electricity consumption is consumed by industry and motors account for about 75 per cent of this consumption. Therefore, increases in motor efficiency can have a significant impact on electricity savings for residential and commercial but especially industrial motor applications.

Duty cycling, speed control, power factor correction, energy efficient motors and efficient mechanical operation are all energy management methods that can lead to lower energy costs and longer equipment life.

Duty Cycling

Some applications require a motor to operate at full load for a period of time, followed by a period where the motor operates under a no load condition. In this case, energy can be saved by stopping and restarting the motor at each cycle. This stopping and starting of a motor is known as "duty cycling".

Efficient Operation and Maintenance

Any systematic maintenance program should start with an energy audit of motor systems in order to establish what energy management activities are necessary and in what order they should be carried out.

Each motor in the building or plant should be tested for the following:

- starting characteristics;
- operating current;
- operating temperature of motor and bearings;
- ventilation; and
- connections and contactors.

Regular checks can detect changes in the motor's usual performance and include:

- noise level of operation;
- time required to reach operating speed; and
- vibration level.

Those interested in pursuing the subject of energy efficient motors should consult Module # 4 of this series.

Lighting

Light sources can account for up to 60 per cent of total electrical consumption in a typical office building.

The most important areas of potential improvements in any lighting system include:

- reduced lighting time;
- replacement of present lamps with lower wattage units;
- reduced illumination;
- bulk relamping;
- positioning light sources to provide better illumination on specific tasks;
- improved power factor. (As a minimum standard of energy efficiency, all lighting fixture ballasts should have a rater power factor of not less than 90 per cent); and
- feeders and subfeeders which minimize copper losses through the use of higher distribution voltages and larger conductors.

Those particularly interested in this aspect of electrical systems should consult Module #2 (Lighting) of this series.

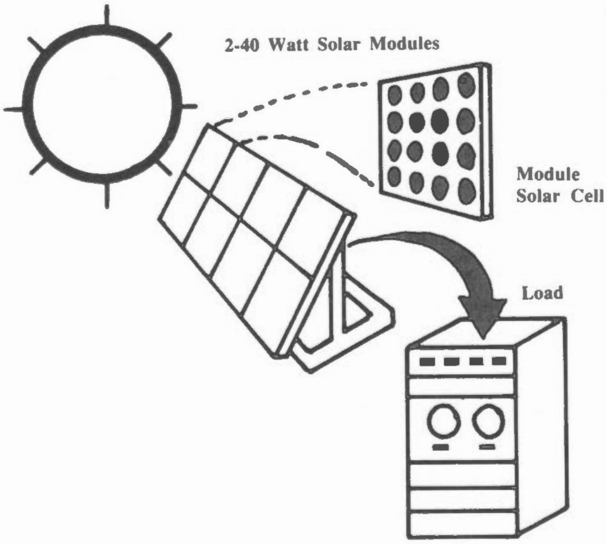
Photovoltaics

Electricity, which is essentially the flow of electrons within electrical conductors, can also be produced through what is known as the photovoltaic or PV effect (Figure 23). This effect allows the direct conversion of sunlight into electricity and is most commonly exhibited in materials called semiconductors.

The photovoltaic cell is designed and constructed in such a way that when sunlight strikes the cell, electron flow is created. If an external circuit is connected to the front and back of the cell, an electric current will flow. Typical PV cells generate approximately 0.5 V and generate a current flow of 2 amperes. Higher currents and voltages are obtained by interconnecting groups of cells in series or in parallel.

A typical solar module capable of producing 35 watts has a length of 100 cm, a width of 40 cm, a thickness of 4.5 cm and a weight of 5.5 kg. A 1 kW system is 4 meters long by 3 meters wide and includes 30 modules. The photovoltaic cells are protected from the environment by tempered glass and special films which allow them to withstand the most rigorous climatic conditions. A typical system includes a group or “array” of modules, batteries for storage and a charge controller to regulate the flow of electricity.

First used in connection with the U.S. space program, photovoltaics have gradually penetrated more and more earth bound applications and can be, in some cases, an economic alternative or supplementary source to conventional energy supply systems. Investment costs per kW in photovoltaic systems are generally greater than for conventional systems.



Typical Photovoltaic System
Figure 23

Energy Audit Methods

The implementation of an energy management program in buildings and plants should include the following basic steps.

Information Gathering

The first step to identifying potential energy management opportunities involving electrical systems begins with the gathering of historical electrical consumption and demand data. Analyzing this information with respect to local electric utility rate structure and billing practices will yield important information relating to costs and possible savings. The use of distribution system layout plans incorporating subsequent modifications will help to identify and locate system components.

“Walk Through Audit”

The walk through audit helps to identify such energy management measures as turning off lighting fixtures, fans or other types of equipment when not in use. It is generally more meaningful if objective people are involved in this exercise, people new to the facility but familiar with energy management. In large office buildings with numerous tenants, this may eventually involve specific arrangements with each tenant in order to properly evaluate working habits and maintenance and cleaning schedules.

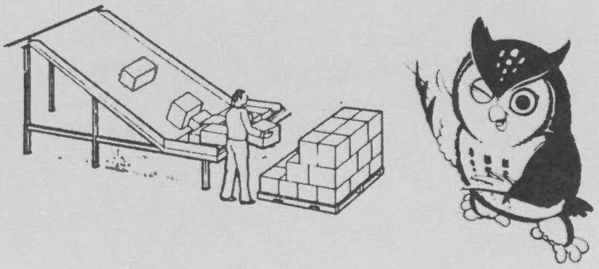
The walk through audit can also indicate whether a detailed survey of all electrical system components is required. At this time, preliminary plans to install additional metering facilities can be formulated. The walk through audit can also identify dangerous conditions, such as loose electrical connections, faulty electrical contacts, or an over abundance of dirt and dust and poorly ventilated spaces and equipment.

Diagnostic Audit

In most cases, the justification for upgrading electrical conductors, correcting power factor or installing energy efficient transformers and motors will not be possible until a detailed cost/savings analysis is completed. This type of analysis is known as a “diagnostic audit” which involves a more detailed investigation of promising energy management opportunities.

Refer to the checklist in the last section of this module. This checklist will assist in conducting such a diagnostic audit. Calculations to determine either simple payback or more complex return on investment results will help to determine the economic viability of many energy management opportunities.

EQUIPMENT SYSTEMS



This section examines the major types of electrical equipment which comprise major electrical systems. These include: meters, electrical conductors, transformers, motors, lighting fixtures, heating elements, capacitors, load controllers and emergency and uninterruptible power supplies.

Meters

Meters are essential to determining the status of an electrical system. Depending upon the system and the specific requirements, meter readings can be taken conveniently and without any power interruption, either by connection to conductors or by the use of clamp-on instruments.

Meter readings are usually taken at the service entrance, on a particular feeder and near equipment that needs to be monitored.

Full power surveys should be performed on a periodic or annual basis, preferrably by specialized firms who can review an electrical system's operating characteristics and indicate potential trouble spots.

Maintenance Meters

An effective maintenance program can be carried out with a minimum number of meters and instruments. Three types of meters are generally recommended: the clamp-on volt-amp meter, the hand-held multimeter, and the insulation tester.

The clamp-on volt-amp meter (Figure 24) measures current flow through a conductor and can be used without de-energizing equipment. This means that loading levels can be assessed without any service interruption. Digital, clamp-on meters can read up to 1000 A, and 750 V ac or 1000 V dc. Some perform well in rugged environments and for their cost are quite accurate. Most types of readings from hand-held meters are within two per cent, which is sufficient for most electrical maintenance purposes.

The second general-use meter is the multimeter (Figure 25). The multimeter is an excellent diagnostic tool to help determine voltages (ac and dc) and resistances at various system or apparatus points. For example, the multimeter can measure voltage levels at a power distribution panel or confirm voltage and resistance levels inside a breaker or a starter. Digital multimeters can perform many functions, such as the measurement of frequency, ac & dc volts, current and resistance. They are relatively low-cost meters and their accuracy, for most types of readings, is within three per cent.

Typical Clamp-On Volt-Amp Meter
Figure 24

Typical Multimeter
Figure 25

The insulation tester (Figure 26) measures the insulation resistance of both a piece of apparatus and electrical conductors. Such readings, taken and recorded at regular intervals, normally indicates if there is any deterioration in conductor insulation. Electrical equipment which operates in factories or buildings where chemicals, heat, steam, or other agents accelerate the deterioration of the conductor's insulation should be regularly examined. Such a procedure can help prevent costly equipment failures and production downtime. Insulation testers are moderate in cost and their accuracy is usually within a range of three per cent.

In-House Meters

In-house energy consumption and demand meters are often used for spot measurements or for specifically monitoring equipment and systems.

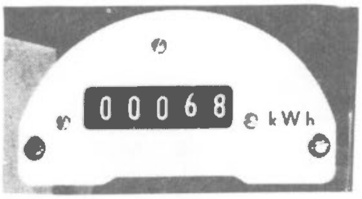
Energy Consumption or Watthour Meters

Energy consumption meters register average electricity over time to indicate energy consumption. They measure watthours in both dc and ac systems.

The energy consumed in a kilowatthour is recorded on a register. The most common types of registers are the four- and five-pointer registers.

Meters with numerical cyclometer dials (Figure 27) are often used when personnel are not familiar with the use of register type meters. Low-cost energy meters give current measurements up to 200 amperes. Above this level, more expensive current and potential transformers have to be used. Energy meters are very accurate — most to within ± 0.3 per cent.

Typical Insulation Tester
Figure 26



Typical Cyclometer Dial
Figure 27

Demand Meters

Watthour demand meters combine, within a single unit, a wattmeter and a timing element. These meters measure in kWh the energy consumed during a given time interval, usually 15 or 30 minutes. This measurement of energy per time interval, indicates the average power in kW during the same period. These meters can be of the indicating or recording type. Demand meters are slightly more expensive than energy meters and their accuracy is generally within one per cent.

Pulse Meters

Pulse-operated demand meters are used for single circuit measurements or as part of a system which combines or totals the demand of several circuits. They are comprised of a demand registering mechanism and a timing mechanism which determines pulse intervals. Pulse-operated meters, just like demand meters, can be of the indicating or recording type. For complete monitoring, electronic recorders are also available which can store pulses for analysis on small computers. Pulse meters are moderate in cost and have the same level of accuracy as standard demand meters.

Instrument Transformers

Instrument transformers insulate and therefore isolate meters when high voltages or high currents are involved. They constitute an important part of the metering installation for most commercial and industrial applications. Potential or voltage transformers are used with voltmeters or with the potential coils of wattmeters. Current transformers are used when the current to be measured is greater than the current which can be carried by the wattmeters or ammeters current coils, or where it is desirable to locate the unit at an appreciable distance from the main circuits, such as on switchboards. Instrument transformers reduce primary voltages and currents to easily-metered values and provide a means for combining them.

Conductors

A good conductor is a wire material which, by design, has low resistance characteristics, is sufficiently lightweight, and has high tensile strength. Copper and aluminum conductors, which possess these characteristics, are used extensively in most electrical applications. Aluminum conductors, however, must be installed by electricians familiar with solderless fittings and other aspects of its use.

Conductor Sizes

There is both solid and stranded conductor. Stranded conductor, which consists of several smaller solid wires twisted together, is used to provide extra flexibility in larger conductor sizes. These sizes are standardized and can be as small as 0.100 mm in diameter, with each successive wire size increasing by a factor of 1.122. Conductor diameters are expressed in millimeters (mm) and cross-sectional areas in square millimeters (mm^2) . The American Wire Gauge (AWG) system, which is still in force in the United States, was used in Canada prior to the adoption of the metric (SI) system. According to the AWG system, conductor sizes started at a diameter of 0.005 inches and each successive wire diameter increased by a factor of 1.123. The area of a conductor was expressed in "circular mils", each of which is equivalent to the area of a conductor having a diameter of .1 mil or one thousandth of an inch. See Table 2.

Insulation

In addition to being either solid or stranded, conductor can also be bare or insulated. Bare conductor is used in some aerial circuits or in areas where there is little possibility for the conductor to be grounded or otherwise shorted, since electricity will always follow the path of least resistance. Conductor used in homes, offices, plants and buildings are normally insulated with a synthetic rubber or vinyl "jacket". Some types of insulation also offer protection, as in the case of steel or aluminum armor which surrounds the conductor. Table 3 illustrates the characteristics of some of the more common types of insulated wires used in buildings and plants. A variety of typical conductors are shown in Figure 28.

a) Non-Metallic Sheathed Cable

b) P.V.C. Insulated Conductor

c) Armored Cable with Polyethylene Insulated Conductors

d) Covered Armoured Conductor Insulated with Polyethylene

Samples of Various Insulated Conductors
Figure 28

Transformers

Electrical transformers, which are used to raise or lower the voltage on an ac circuit, have internal losses which are consequently dissipated as heat. Two basic cooling methods are used to lessen these losses within the transformer. These are liquid-immersed or dry-type cooling systems.

Practically all industrial transformers are of three-phase construction. Single-phase transformers are generally used inside buildings to supply lighting and small electrical loads.

Liquid-immersed

In liquid-immersed transformers, the windings are immersed in a liquid contained in the transformer tank. The liquid absorbs the heat which is then dissipated/absorbed by natural convection or through a variety of other means such as fans and cooling coils. Outdoor substations are usually equipped with liquid-immersed transformers.

PCBs

PCBs or polychlorinated biphenyls were used extensively for many years as cooling liquids in transformers, regulators and capacitors. These liquids were found to be environmentally questionable and have since been banned for use in new electrical equipment.

Transformers which contain cooling liquids with more than 50 parts per million of PCBs must be labelled as PCB-contaminated. Once so labelled, it can be legally used in Canada for the balance of its operational life. Such transformers must be checked regularly for dielectric leaks and must be submitted to a more rigorous maintenance schedule. Information concerning routine inspections and steps for cleanup of PCB liquids is available from Environment Canada.

Retrofilling PCB-cooled transformers, which involves draining the PCBs, flushing the transformer and refilling it with a non-PCB liquid, has generally not worked. This is because in a short time, residual PCBs from various parts of the windings leach into the new liquid, which soon exceeds the allowable limit of 50 ppm. The only known way to keep the new liquid below limits is to continue periodic filtration to remove PCBs from transformer oil. While this has been considered generally uneconomical, the recommended solution has been to operate the transformer to the end of its operational life and then replace it with a new unit. The possible exceptions to this procedure are transformers which are located in areas where removal and replacement without detanking the coils would be extremely difficult, such as an upper-floor electric closet in a high-rise office building.

Dry-Type

Dry-type transformers dissipate heat losses directly through conduction and natural convection. They are more costly than liquid-immersed units, but do not require any vaults or special venting. They require minimal inspection of air circulation or dust accumulation, but require none of the maintenance practices of liquid-filled units. The capacity of their insulation to withstand lightning or surge overvoltages is only about half that of liquid-immersed units. Dry-type transformers are sold in a number of temperature-rise classifications. Transformers with lower temperature rise ratings have lower winding losses and longer life expectancy. These advantages usually offset their higher initial cost.

Table 4 compares liquid and dry transformers with respect to price, size, losses and performance.

Transformer losses

Manufacturer's catalogues do not specify losses in small transformers, normally below 500 kVA.

Larger units are made to specification and are sold according to the least evaluated cost formula. According to this formula, the value of the transformer's "no load" and "load losses" is added to the estimated cost of the transformer itself, in order to arrive at a total evaluated cost.

For any given transformer, with selected input and output voltages and maximum temperature rise, the application of this formula requires an estimate of the transformer's operating time and the cost of electricity over the duration of its estimated life. The manufacturer must also estimate the price differential between standard, high-core loss or low-core loss units. As always, higher-projected electricity costs will favor the specification of more energy efficient transformers.

The purchase of a transformer requires teamwork between the purchaser, the utility and the manufacturer, to ensure that the most accurate information is used for the calculation of the total evaluated cost.

Motors

Since motors convert electrical energy into mechanical energy, choosing the right motor for a given application requires that several factors be considered. These include requirements of the driven equipment such as starting, acceleration, speed, load, and duty cycling, and other considerations such as service conditions, desired motor efficiency, effect on power factor, and cost limitations.

From a system distribution perspective, there is a practical maximum motor size for each source of electrical supply. For example, 2 hp is the maximum acceptable size on a single-phase, 120 V circuit; just as 10 hp is the maximum acceptable size on a 240 V single-phase circuit.

Maximum limits are determined by distribution voltage and the capacity of the transformer used.

Most electric utilities place a limit on the size of a motor they will allow on a single-phase line because of the heavy surge currents associated with motor start up. Such surges create disturbances which can adversely affect equipment owned by the utility and even their other customers. It is therefore advisable to check with your local electric utility before proceeding with the installation of a large motor.

Protection

The subject of motor protection is covered by numerous sections in the Canadian Electrical Code. Most ac motors which are started at full voltage exhibit a high starting current. This "surge current", as it is commonly called, can attain values of up to eight times the rated full-load motor current. Surge current then drops to the rated value as the motor reaches full speed. It follows, therefore, that two types of protection are required in motor circuits. The motor branch circuit must let the in-rush current flow but must also protect the circuit against overload. Likewise, additional protection must be provided at the motor against overloads from different causes.

Speed control

Electricity consumed by a motor is proportionate to its speed. The higher the speed, the higher the electricity consumption.

The availability of a large number of adjustable speed drives has encouraged studies on the economics of such drives in flow control applications. In such applications, the use of adjustable speed drives can save a considerable amount of energy where the driven equipment is operated with sufficient partial load duty. In such cases, the higher total efficiency of the combination drive system and driven equipment can be utilized to advantage.

Flow control applications include variable air volume fans, feedwater pumps and transfer pumps.

A detailed cost evaluation was performed where the costs for drives, wiring and power supply, space, flow control equipment (such as valves and dampers) as well as electricity, were compared on a yearly basis for constant vs adjustable speed drives.

Adjustable Speed Drives

Adjustable speed drives were found to be economically feasible in most applications, even at relatively low electricity rates. Energy savings in Canada, attributable to adjustable speed drives, average 2.6 per cent for all industrial electricity consumption. Savings ranged from 0.5 per cent in iron and steel mills, smelting and refining, up to 10.6 per cent in petroleum refineries. An estimated 2.0 per cent of all commercial energy consumption could also be saved; this ranged from 0.6 per cent for department stores, retailers and services, up to 7.7 per cent in hospitals.

Motors are dealt with in greater detail in Module #4 (Energy Efficient Electric Motors) in this series.

Lighting

While natural light can be used in some general locations and workplaces, artificial light sources are used to supply most illumination in commercial, institutional and industrial establishments.

Artificial light sources vary considerably in their ability to deliver light from a given amount of electrical energy. Table 5 summarizes the more commonly-utilized light sources.

For those interested in lighting equipment and systems, consult Module 2 of this series, titled "Lighting".

Electrotechnologies

There have been significant recent advances in a number of important electrotechnological applications. Major electrotechnologies include resistance heating, induction heating, infrared heating, heat pumps, mechanical steam recompression, plasma arcs, electric arcs and microwaves.

These advances have been spurred by developments in the computerized supervision of many industrial processes, coupled with developments in industrial automation equipment. The result of this is that electrotechnologies can now lead to increases in the energy efficiency of many thermal processes. By providing heat where and when it is needed and in the exact amount required, electrotechnologies can often replace more cumbersome and less energy-efficient energy sources.

The installation of industrial heat pumps and mechanical steam recompression systems in a number of industrial processes can result in dramatic increases in energy efficiency. Refer to modules #8 (Steam and Condensate Systems) and #11 (Refrigeration and Heat Pumps) in this series. They examine in detail how to improve the energy efficiency of such systems.

Each electrotechnology has specific applications. For instance, electrotechnologies such as resistance and infrared heating account for about 75 per cent of the total number of electrotechnology applications. The following discussion will be confined to their basic characteristics.

Resistance heating is the best known and the most commonly-used electrotechnology. There are two basic types of resistance heating: direct and indirect. With direct heating (Figure 29), an electric current passes through the material being heated. The heating effect or heat generated is equal to:

$W = I^2 R$ where,
W = watts (W)
I = current (A)
R = resistance (Ω)

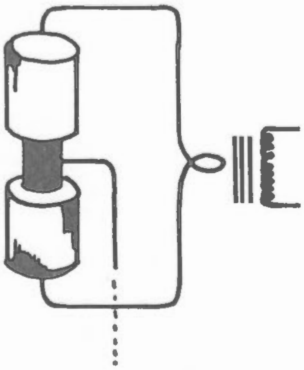
Examples of direct resistance heating include the preheating and heat treatment of metals, glass melting, soldering and steam generation.

With indirect resistance heating systems (Figure 30), heat is generated from special wires or heating elements. This heat is then transferred to the material or area to be heated.

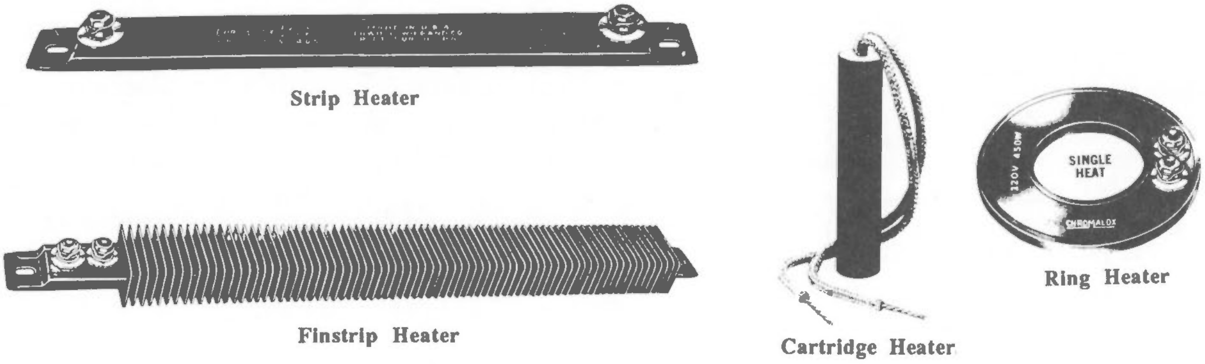
Examples of indirect heating include space heating, ovens, dryers and many other applications.

Infrared heating (Figure 31) is an electrotechnology which transmits heat directly, by radiation, from a high-temperature energy source (350° C to 2200° C) to the substance being heated, without any significant direct absorption by the environment. This energy source can be dissipated by resistance wires or resistors imbedded in pyrex, ceramic, steel, silica, or tungsten filament lamps. Infrared systems are used principally in surface heating applications such as paint drying and polymerization. It can also be used for space heating applications in areas such as garages, plants with high ceilings or near loading doors that are normally difficult to heat by conventional convection systems.

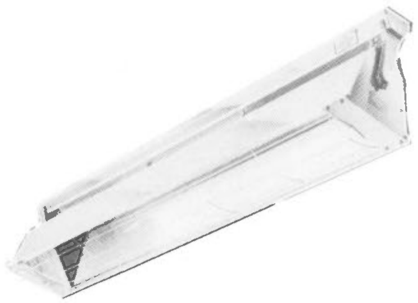
Direct, indirect and infrared heating provide heat directly where it is required and as a result have energy efficiencies higher than 90 per cent.



Example of Direct Heating
Figure 29



Example of Indirect Resistance Heating
Figure 30



Infrared Heater
Figure 31

Electric Heater Selection

Electric heaters, used for resistance and infrared applications, must be selected according to function, type, capacity, operating medium, operating voltage and operating temperature. For example, a tank holding a weak solution at 500° C might require an immersion heater. The principle categories of heater are summarized in Table 6.

Industrial heaters vary from a few hundred watts to several hundred kilowatts in capacity. Depending on their capacity, they are usually available for all standard single and three-phase distribution voltages. Manufacturers normally supply product guides for the proper selection of electric heaters for hundred of different applications.

Capacitors

Electrical capacitors (Figure 32) are very simple devices. They have no moving parts and consist of plate-like electrodes separated by an insulating material.

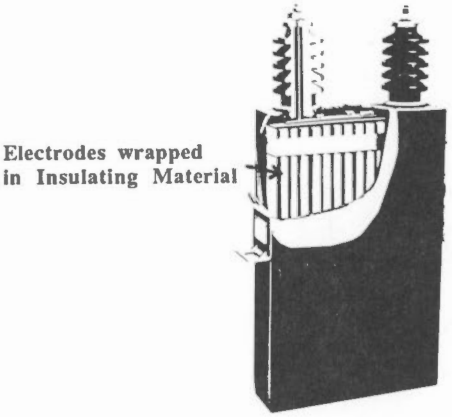
Capacitors reduce power costs, raise voltage levels and release electrical system capacity. They are easy to install, have relatively low electrical losses, and require very little maintenance.

Maximum energy management benefits are obtained when capacitors are installed at the point of electrical load in order to reduce power factor penalties and heat loss in the feeder.

The larger the capacitor, the more slowly the heat produced near the center of the capacitor can be conducted to to the outside container and dissipated. This factor limits the economical size of capacitors to approximately 15 kvar for 240 volt units and 60 kvar for 600 volt units. Large electrical capacity capacitor bank installations are comprised of as many small units as necessary. This necessitates that capacitors be located in well-ventilated areas.

Capacitors are designed for voltages ranging from 240 volts to 34.5 kV for use in industrial plants, buildings and utility distribution systems. Indoor and outdoor units are available.

Capacitor selection and location requires careful consideration. Several factors, including savings, released kW and kVA, and cost for different installation alternatives should be considered. Low voltage capacitors cost more per kvar than higher voltage units. On the other hand, correcting the power factor at the service entrance might require less capacity than at the individual locations since most plants only have some 60 per cent of the connected load operating at the same time. The cost of correcting at the service entrance might require switching capabilities to match the correction capabilities with the load.

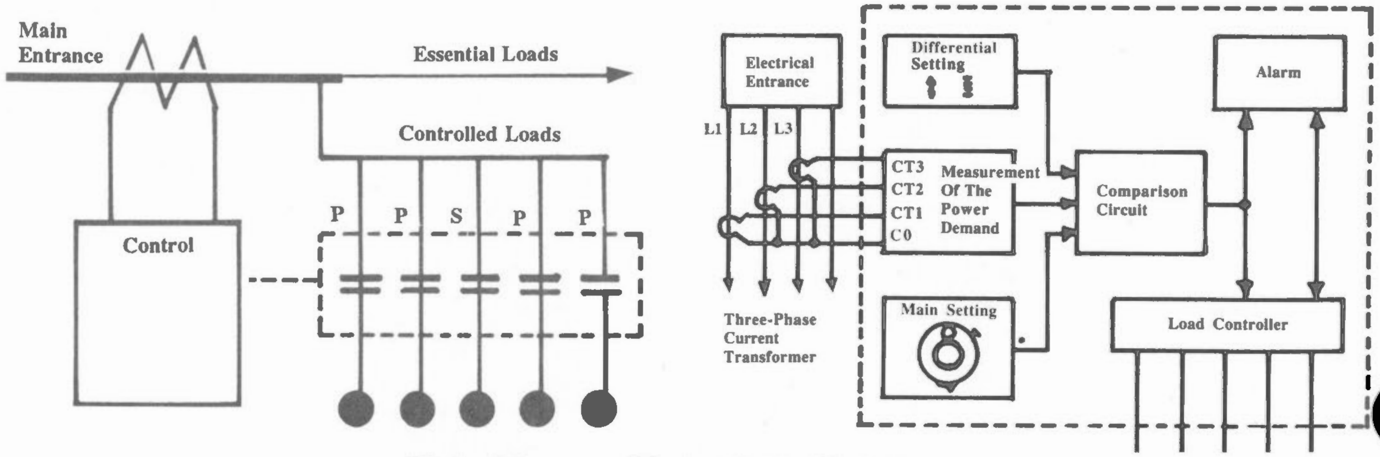


Typical Electrical Capacitor
Figure 32

Load Control Equipment

The essential purpose of load control equipment is to limit the peak power demand of an electrical installation.

A typical system measures the power demand and compares it to a maximum reference level which has been preselected by the user. Whenever the measured demand exceeds this level, the control equipment automatically disconnects or sheds non-essential loads on a priority basis until the peak power demand has been decreased to the desired level. As peak power demand falls, these circuits are automatically re-connected (Figure 33).



Wiring Diagrams of Typical Control Systems
Figure 33

There are three general categories of energy management and control systems (EMCS): localized, remote limited, and multifunction or centralized computer-based. Localized systems provide independent control for specified systems and equipment and are relatively low-cost systems. A limited function demand controller, on the other hand, interfaces with numerous energy-consuming devices and systems to limit electrical demand and is typical of remote limited and multifunction control systems.

Many of these controllers are programmable. Centralized systems are generally operated from a master control room containing a minicomputer or a microcomputer. These computers monitor and control various points according to pre-programmed instructions or a man-machine interface. They can be programmed to perform any number of control functions (outputs), depending upon the number and type of input/output circuits, the size of the memory and the capacity of the processing unit.

The selection of a system for a given application usually involves a study of several factors such as: its adaptability in the control of the given functions; its maintainability through in-house or outside personnel; its reliability expressed in terms of a low breakdown or downtime rate; its expandability to meet future needs; and its programmability or the ease with which existing programs can be modified.

The cost benefits of a control system depend on the analysis of the following factors:

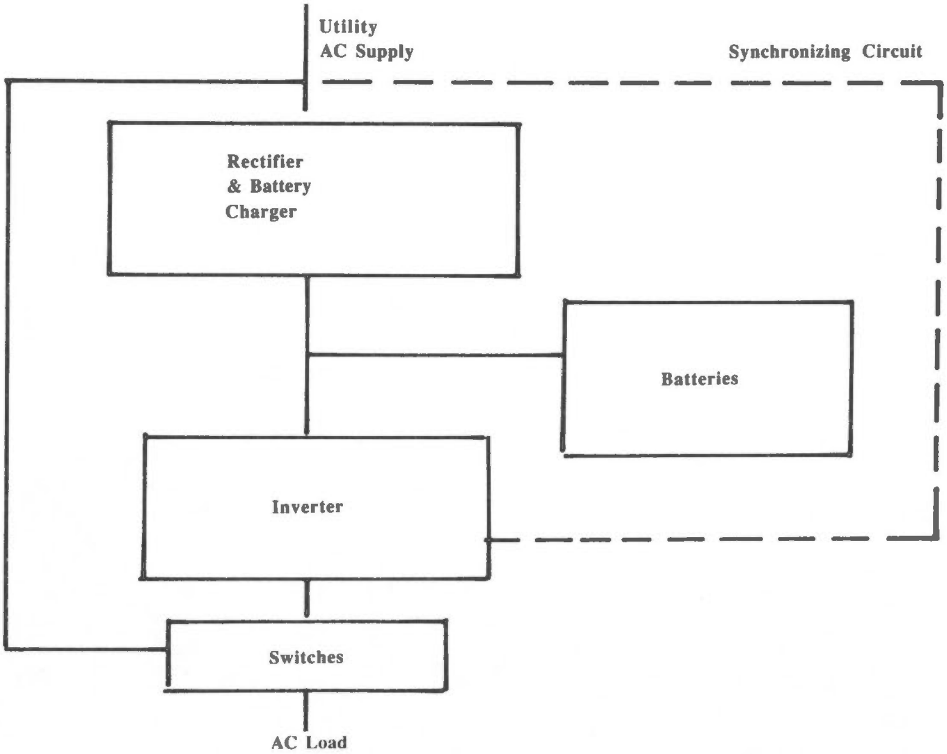
— estimated savings in electricity costs;
— capital cost of control installation; and
— maintenance cost of installation.

Emergency and Uninterruptible Power Supplies (UPS)

Emergency and standby power generators ensure that essential service is maintained during prolonged power interruptions. They are generally powered by a gasoline, diesel or natural gas combustion engine. A switch, (usually automatic) transfers selected loads from the utility supply to the generator output whenever there is an interruption in service.

Uninterruptible power supplies (Figure 34) are installed to ensure that essential services will not be hampered by power interruptions which may last only a fraction of a cycle.

Systems which usually cannot tolerate interruptions without damage or serious consequences include boiler flame failure and controls, electronic process control instruments, computers, critical alarms, analyzers, potentiome-



Typical AC UPS Circuit
Figure 34

ters, critical communications equipment and some types of relays and solenoids.

Uninterruptible power supplies can supply dc or ac. Alternating current UPS's are quite popular since ac loads which they supply most likely do not have to be modified. They are comprised basically of a solid-state rectifier and battery charger, a dc battery and a solid-state inverter.

Alternating current UPS's are generally available in 250, 500 and 1000 volt-ampere sizes. Each size can be purchased with a series of options. Battery options can back-up the full load for a few minutes up to several hours. Some of the other options include a remote alarm, modifications for output frequency and overload surge capacity for electric motor supply. UPS systems are available in modules which can be customized to suit the user's exact requirements.

ENERGY MANAGEMENT OPPORTUNITIES

Energy Management Opportunities is a term used to represent the many ways and means of utilizing electricity wisely to save money. A number of energy management opportunities will be discussed in this section. These have been divided into the categories of Housekeeping Opportunities, Low Cost Opportunities and Retrofit Opportunities. The opportunities mentioned and the examples given in these three sections, while not exhaustive, should assist those associated with managing and operating electrical distribution systems in plants and buildings to relate the information found in these sections to their own specific situations.

Housekeeping Opportunities

Housekeeping opportunities are energy management actions that are performed on a regular basis — never less frequent than once a year. The following are some typical energy management opportunities that fall into this category.

1. Know your electricity bill. Electricity bill management is the start of an effective energy management program. Make sure that all pertinent aspects of a utility bill are well understood.
2. Turn off all electrical equipment which is not in use. This refers to such devices as fans, coffee pots, displays, lights, pumps and compressors.
3. Permanently disconnect all unused equipment and devices until they are needed.
4. Identify all major pieces of equipment within the electrical distribution system. (Such as motors, transformers, uninterruptible power systems and switchgear).
5. Establish an electrical system maintenance program.
6. Initiate employee-involved energy management programs.
7. Reduce electricity demand by rescheduling activities or operations to lessen peak demand.

Housekeeping Worked Examples

1. Know your electricity bill.

An important element of any electrical energy management program is the establishment of a record of past electricity billings (preferably covering the last twelve-month period) for each meter location.

The Electricity Cost Data worksheet can be used for this purpose. Utility bills can be used as a source of data. If these are not available, the utility will normally supply the required billing information upon request. The following worked example shows one year's billing data for a typical industrial plant.

Billing Summary

The Electricity Cost Data Worksheet #1 at the end of this section details a sample company's billing information for a 12-month period. It reports that the company's kWh consumption varied from a high of 1,944,100 kWh in January to a low of 1,125,360 kWh in August. Correspondingly, monthly peak demand ranged from a high of 4,500 kW in January, to a low of 3,126 kW in August, during which production was slow.

Billed demand, measured in kW, exceeded actual kW demand during the months of March, April, September and October. During these months, the power factor specified in the local utility's rate (90 per cent) exceeded the actual kW demand. This was due to the fact that the plant was operating at a power factor lower than 90 per cent. During these months, special equipment with low-power-factor motors was in operation. The customer was therefore penalized through the application of the power factor clause (kVA * 90%). (See section: "Power Factor — Sample Calculation")

The cost of electricity purchased during this period totalled $975,488.00 — an average of $0.053 per kWh.

Rate

The utility rate used for these billing calculations is a variable block rate. This amounts to:

$5.00 per month per kW of billing demand;
$0.06 per kWh for the first 120 hours of the billing demand;
$0.04 per kWh for the next 7800 kWh ; and
$0.03 per kWh for the balance of all consumption.

In this case, billing demand is calculated on the basis of the actual monthly maximum kW demand, or the kVA demand at 90 per cent power factor, whichever is greater.

Efficiency Considerations

This demonstrates that improvement in power factor would have reduced the billing demand and therefore the electricity bill during the four months when the billed demand exceeded the actual kW demand. Since it was special equipment operating during the four months that lowered the company's overall power factor, the cost benefit of installing capacitors directly on this equipment becomes apparent.

Elimination of the power factor penalty for these four months amounts to $8,133.00. A preliminary estimate indicates that the cost of corrective capacitors on the low-power-factor large motors would cost some $7,500.00. This investment would result in a payback of less than one year.

This saving is calculated by subtracting the monthly electricity bill, after power factor has been corrected, from the bill shown on the cost data worksheet for each of the four months concerned. For example:

Total savings:
$2072.00 + $2029.00 + $1978.00 + 2054.00 = $8133.00

Load factor:

$$\frac{1,944,100}{4500 \times 720} \times 100 = 60\% \text{ in January}$$

and

$$\frac{1,125,360}{3126 \times 720} \times 100 = 50\% \text{ in August}$$

Increasing the load factor, which averaged 60 per cent in January and 50 per cent in August, would also have lowered the electricity bill by lowering demand costs and shifting more of the consumption down to the last step of the variable block rate, which is at $0.03 per kWh.

This could have been accomplished with the demand control technique, if electrical loads in the plant had been suitable. As indicated earlier, the use of load control techniques to shave peaks necessitates the examination of load profiles on peak days of the month in order to best determine its potential.

2. Turn Off All Electrical Equipment

In general, savings from this practice are directly related to the number of kilowatts shut off and the total time that equipment is de-energized. The savings can be estimated by using the average price per kWh found on the Electricity Cost Data Worksheet #1 . A typical Shutdown Checklist is seen on Worksheet #2. Such lists should be tailored to suit individual needs.

3. Disconnect Unused Equipment.

Certain electrical equipment and devices, such as ventilation fans in storage areas or in unused production units, are sometimes not required for extended periods of time. In such cases, disconnecting them from the electrical supply is a safety measure that can prevent unauthorized persons from switching on this equipment and possibly causing injury. It can also be a source of cost savings, such as in the case of transformers which, when energized, continue to consume electricity.

4. Survey The Electrical Distribution System

In addition to analyzing billing information, surveying an electrical distribution system is a must — especially in those cases where original electrical distribution plans have been modified over the years. This is something that can be conducted by qualified plant or building maintenance personnel. The survey should cover all items, including: the plant or building substation, the main switch and protection and finally each branch circuit.

The results of this survey, which should become part of the records, may indicate problem areas which require attention. These can include:

- motors which are running too hot and take too much time to reach normal operating speed;
- lighting fixtures which flicker or which produce very low lighting outputs;
- loose electrical connections and poor contacts which increase losses and can produce overheating, arcing and perhaps lead to dangerous conditions and electrical equipment breakdown. Infrared thermal scanning is sometimes used. It allows, through qualified interpretation of thermograms and real-time photographs, the early detection of faults or "hot spots". If this is the case, problems can be rectified and equipment repaired before costly breakdowns occur;
- dusty, poorly ventilated locations for electrical equipment including batteries which can lead to explosive atmospheres and accelerate the deterioration of electrical and electronic components. Such locations must be kept relatively dry. Appropriate ventilation prevents the build-up of heat, humidity and corrosive gases;
- capacitors which are poorly ventilated and located in dusty locations; and
- improperly grounded circuits and apparatus due to loose or corroded ground connections or other causes.

5. Establish an Electrical Maintenance Program

This is a normal follow-up to the survey detailed above which has pinpointed those measures needing immediate attention, normal maintenance, and longer term improvements. Conditions which can result in danger to life or equipment are always a primary concern.

Depending upon operating conditions, electrical maintenance activities can be scheduled on a periodical basis or can be carried out during planned shutdown periods.

An electrical maintenance program should include:

- a regular check of electrical and lighting circuit voltage levels. The proper operation of lighting equipment can be asserted simultaneously;
- a regular quality inspection of insulation quality around conductors and electrical apparatus;
- a lubrication schedule for motors, since poorly lubricated motors have increased friction losses and may incur damage;
- a regular check of all battery locations. If they are "wet" type, the electrolyte must be maintained at the proper level;
- a regular check of all equipment and transformer rooms for temperature, humidity, vibration and atmosphere;
- a regular check of transformer loadings and other transformer operating conditions. Transformers must be properly ventilated. If located outside, shading should be provided during warmer months in order to reduce losses and prevent heat build-up. Transformers which are to remain unloaded for some time should be de-energized for that period;
- a regular maintenance program of electrical equipment such as elevators, escalators and indoor and outdoor lighting installations, according to manufacturer's recommendations;
- a regular check of all ground connections; and
- a regular check of all capacitors and capacitor switching installations.

6. Initiate an Employee Involvement Program

Most individuals in a plant or building contribute directly to electricity consumption. What this means is that every individual has some control over how much electricity is consumed. Effective action in energy management means concerted action. This can generally be achieved by communicating with the personnel through internal memos, reminder signs, meetings, and personal contacts. An energy management committee, involving all department heads concerned, is an energy management technique that has been proven to work well in many industries and establishments.

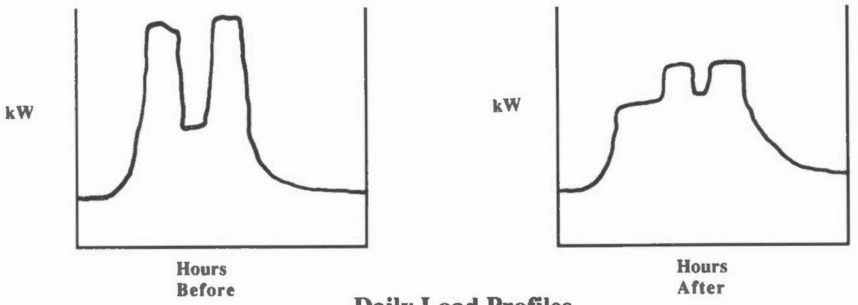
7. Reduce Electrical Demand by Rescheduling Activities or Operations (Worksheet #3)

An analysis of electricity consumption obtained through a billing summary and from the loads documented in an electrical distribution system survey may indicate housekeeping measures which can lower electricity demand while not necessarily incurring significant expenses. For example, it may be possible to stagger the operation of two electric ovens and thus lower the demand peak which they otherwise would create.

For example, from the sample Rescheduling of Activities Worksheet it can be seen that the peak load of an industrial plant reached 650 kW from 10 to 11 a.m. and from 3 to 4 p.m. on days when production was at its maximum. An analysis of the profile and of the loads operating during the peak demand period revealed that lighting, small motors, and miscellaneous loads were contributing a total of 180 kW. Conveyors and a kiln added another 280 kW. None of these loads could be conveniently rescheduled without hampering production. On the other hand, two ovens were each contributing 90 kW of demand while a water heater contributed 10 kW of electrical demand.

A study of the production process indicated that the ovens could be staggered during peak periods, thus reducing the peak demand by 90 kW . Also, one water heater element of 5 kW could be permanently disconnected since the storage facilities were large enough to supply the required needs with a 5 kW heater operating during most of the 24 hour period.

Such measures reduced the peak by 95 kW which resulted in a monthly saving of $475. Note that only the cost of a billing kW is used in the preliminary estimate of savings. Where a variable block rate is used, this would be a conservative estimate since, as shown previously in the rate section, a higher demand shifts more of the kWh consumption to the higher priced first block. A lower demand reduces not only the kW demand bill but also lowers the average kWh price. No special investments were required, other than to issue special instructions to those operating the ovens. Energy consumption was essentially the same after the staggering operation as before. Figure 35 shows the before and after daily load profile on a typical peak day.



Daily Load Profiles

Figure 35

Low Cost Opportunities

Implemented "Low Cost Opportunities" are energy management actions that can be performed once and for which the cost is not considered excessive. The following is a typical energy management opportunity under this category.

Install Simple but Effective Load Management Equipment

Installing time clocks on equipment which is only occasionally used can contribute to the lowering of overall electrical demand. For example, if clocks are installed on 40 kW of water heater equipment which will no longer be contributing to peak demands, the savings at $5/kW per month of peak demand would be $200 or $2,400 per year.

The possible additional effects of a variable block rate are neglected in this case. Before using such a method, a study of hot water use patterns and storage facilities must be conducted in order to ensure that hot water will be available for all intended purposes. In this case, water was needed for showers and sanitary purposes and the necessary hot water could be available after each working shift without having to produce any hot water during the four peak hours indicated on the daily peak load profile. As a result, there was no appreciable difference in energy consumption. The cost of installing the time clocks was estimated at $3,700.00. The simple payback of the investment becomes: $3,700 ÷ $2,400, or 1.54 years.

Retrofit Opportunities

Implemented Retrofit Opportunities are energy management actions which can be performed once and for which the cost is significant. The object of this module is to point out those areas where efforts should normally be concentrated and where significant savings are more likely to result. Worked examples have been prepared for some of the listed energy management opportunities while in other cases, only commentaries have been offered. The following are typical energy management opportunities in the retrofit category.

1 — Power Factor Correction
2 — Manage and control electrical demand
3 — Limit voltage drop in circuits
4 — Replace conventional motors with energy-efficient types
5 — Replace conventional transformers with energy-efficient types
6 — Optimize electric motor sizes
7 — Control electric motor duty cycle or speed
8 — Use waste heat produced by electrical equipment

Retrofit Worked Examples

1. Power Factor Correction

The Power Factor Correction Worksheet #4 illustrates the case of a building with a monthly peak demand of 280 kW and a kVA reading of 360. The building has a number of medium-quality fluorescent lighting ballasts and small motors which create a low power factor. A preliminary investigation indicates that it would not be economical to correct the power factor at any location other than near the service entrance.

The overall multiplier indicated on the utility bill is 10. Therefore, the actual consumption is:

Reading x multiplier = actual consumption
280 x qp = 2800 kW
360 x qp = 3600 kVA

Using the kW multiplier (Table 1), the multiplier shown to correct the power factor from 0.77 to 0.90 is equal to: 0.345. The number of kilovars required becomes:

kW multiplier x kW:
= 0.345 x 2800
= 966 kvar

Correcting the power factor from 0.77 to .90 results in a monthly reduction of 440 kW (3600 x 0.9 = 3240 — 2800 = 440 kW). At the demand rate of $5 per kW per month, the monthly savings amounts to $2,200 and the yearly savings to $26,400. In this example, a multiple block rate is used which does not tie in the kWh consumption to the demand component. If such were the case, the savings would be greater since lowering the demand would also lower the average price of a kWh.

Since the cost of capacitors was quoted at $27,198, the simple payback period is 1.03 years.

In the worked example, the savings were projected for the 12-month period. This was possible in this case because the building's electrical consumption did not vary significantly throughout the year. This assumption can only be made after examining the 12-month billing summary because, as was demonstrated in the cost data worksheet, the power factor and hence the power factor penalty clause, are not necessarily constant throughout the year.

It is often advantageous to correct the power factor of a large motor near the motor itself. This reduces the current and therefore losses through the complete motor supply system.

As reported on the Motor Power Factor Correction Worksheet #5, a plant utilizes a major piece of electrical equipment which is a 200 hp, three-phase electric motor. Manufacturer's data indicates that the motor is 90 per cent efficient and a clamp-on volt-ammeter indicates that it draws 199.6 amps at 600 volts.

According to Table 1, the kW multiplier to improve the p.f. from 0.80 to 0.90 is equal to 0.266. Therefore:
kvar = kW x multiplier
Kvar =0.266 x 165.8 = 44.1 kvar

The billing demand is equal to the largest of two quantities: the kVA demand at 90 per cent power factor or the actual kW registered at $5 per billed kW per month:

KVA x 0.9 =
207.2 x 0.9 = 186.5
Or, kW = 165.8
Difference = 20.7 kW

Avoiding the penalty at $5 per kW per month amounts to:

20.68 x 5 = $103.40 in monthly savings.

On a yearly basis the saving becomes:
$103.40 x 12 (months) = $1,240.80

Once again, a simple block rate is used. If a variable block rate schedule were applied, savings would be greater as a result of the lower cost per kWh.

The cost of installing the capacitor directly at the motor circuit was $1,764.00 and the simple payback = $1,764.00/ 1,240.80 per year, or 1.42 years.

2 — Manage and Control the Electrical Demand

In this example (Worksheet #6), the facility has an overall monthly demand of 1,800 kW. An analysis of this demand has shown that a large part of it (1,560 kW) is comprised of essential loads that cannot be deferred or interrupted without disturbing production. The load survey also demonstrates that 50 kW of water heating and 300 kW of bath heating contribute a combined 240 kW to peak demand. Using the load management worksheet to determine possible load factor improvements through better control of electrical demand, it was found that bath heating could be accomplished outside the four daily peak hours. There would be no appreciable difference in electrical consumption since the installation is well insulated. The estimated savings in electrical costs at $5 per kW of peak demand per month totalled:

($5.00 x 240) x 12 = $14,400.00 per year.

The cost of the changes in the installation (added insulation, controls, storage) amounted to $30,000.00. The initial estimated payback period is 2.08 years.

If preliminary indications such as those supplied in Worksheet #6 are arrived at, more detailed analysis is recommended.

Once a preliminary analysis has pinpointed the possibility of peak control and secondary or non-essential loads have been identified, the next step is to determine how non-essential loads can be effectively dealt with. They must be able to continue to perform their useful functions while being deferred or rescheduled. Once this work is completed, it should yield information as to the nature and cost of investment needed, if any, to modify some equipment features. For example, some water storage tanks may have to be added or some electrical circuitry may have to be modified.

Control measures which can be implemented include:

Installing an Energy Management Control System

A- Install Automatic Load Shedding Equipment

The simple rescheduling of a few large electrical loads, as discussed above, may not be possible because the electrical system may only feed small, staggered loads. In such cases, the installation of a remote limited and multi-function system could lower overall electrical demand by automatically disconnecting or shedding secondary loads as demand approaches a preset value. As discussed in the Fundamentals section, the implementation of such a strategy requires an analysis of the facility's load profile and of the loads which contribute to peaks. The identification of essential and non-essential loads and their operating characteristics should help to determine if a load control system is economically feasible.

B — Install a Thermal Storage System

Electrical peaks are sometimes created by thermal equipment which must supply given quantities of heat during certain periods. In some cases, such demand peaks can be trimmed with the installation of storage facilities for the production of electric heat during off-peak periods. The savings in electricity costs have to be sufficiently critical to justify the installation and maintenance of such a system. For more information on this subject, refer to module # 19 (Thermal Storage) in this series.

C— Install a Dual-Energy System

Savings can accrue through the use of space heating systems and processes which are adaptable to the alternate or simultaneous use of two or more energy sources. As discussed previously, a key factor is the availability of dual-energy rates from either electric and gas suppliers. Such rates require that the customer operate two separate systems that can individually assume all heating tasks. This allows the customer's electrical heating equipment to be used during utility off-peak hours.

3 — Limit Voltage Drops

As mention earlier, large voltage drops reduce the energy efficiency of motors, lighting systems and most other types of electrical equipment. Simply stated, limiting voltage drop results in better operating equipment and prolongs useful life. Checking voltage drops with a clamp-on volt-ammeter or a multimeter is a practical way to diagnose operating problems. Voltage readings can be taken at the entrance panel and near the load.

If, for example, these voltage readings are 240 volts and 215 volts respectively, the percentage voltage drop becomes:

$$\frac{240 - 215}{240} \times 100 = 10.4\%$$

This would indicate that problems with end-use equipment located on this circuit could be a result of an insufficiently-sized conductor which is creating a large voltage drop.

4 — Replace Conventional Motors with Energy-Efficient Motors

The Energy Efficient Motors Worksheet #7 at the end of this section compares the replacement of a motor with a similar conventional model or with an energy-efficient type.

In this example, the difference in efficiency between an efficient motor and a standard unit is 94 - 89 = 5%.

Energy costs are $0.05 per kWh and the premium cost of an energy efficient motor is estimated at $450. The simple payback period is therefore 1.6 years.

Electric motors have earned a reputation of being quite efficient. While this is the case, the premium cost of an energy-efficient motor is often compensated through electricity cost savings with acceptable payback periods. This is particularly the case with motors which have a fairly high load factor and operate near their rated output. For more information about this subject, refer to Module #4 (Energy Efficient Electric Motors) in this series.

5 — Replace Conventional Transformers with Energy-Efficient Transformers

The Energy Efficient Transformers Worksheet #8 calculations are similar to the previous comparison between the two types of motors. For instance, a plant manager faces the problem of replacing a 400 kVA transformer with a standard unit (93 per cent efficient) or with a more efficient type (97 per cent) at a premium cost of $4,000. Clamp-on meter readings supplemented by manufacturer's data indicates that the transformer is loaded at 80 per cent. It operates an estimated 4,000 hours per year.

The worksheet shows that the premium for a 400 kVA energy-efficient transformer is repaid in a little more than a year. Average kWh cost was assumed at $0.07. With electricity at half that price, or $0.035 per kWh, the simple payback period would be just over two years.

6 — Optimize Electric Motor Size and Application

Electric motors which are oversized generally operate at low efficiency and low power factors. An electric distribution system survey may help to detect cases of motor underloading which can be remedied, sometimes by relocating some of the motors involved. The survey data can also be used to select the proper motor when existing units have to be replaced. An analysis of load characteristics can also enable the user to choose, with the manufacturer's help, the right kind of motor for the specific application.

7 — Control Electric Motor Duty Cycle and Speed

As previously discussed in the equipment section, it is sometimes possible to reduce overall electricity costs by operating motors on preset duty cycles and with speed control devices. The use of adjustable static frequency drives on pump drive systems can result in a number of advantages including: high efficiency at all pump operating speeds which results in lower operating costs; and greatly simplified preventive maintenance because of the inverter and increased motor protection with electronic devices.

8 — Use Waste Heat Produced by Electrical Equipment

Some buildings are making use of transformer losses in internal substations to contribute to the building heating supply. Likewise, properly-located heat exchangers may help transfer heat from one location to another for space heating or for preheating liquids.

APPENDIX

GLOSSARY

Alternating Current — An electric current that reverses direction in a circuit at regular intervals.

Ammeter — An instrument used to measure electrical current, in amperes.

Apparent Power — A unit of electrical current. A current of one ampere will flow through a resistance of 1 ohm when 1 volt of potential is applied.

Balanced Load — Term used to indicate relatively equal currents in all phases of a multiphase circuit and equal voltages between phases and between each phase and neutral if one exists.

Billing Demand — The demand used by the power supplier to calculate the electric bill.

Block Rate — Rate where the energy and/or the demand are billed in preset groups of units or blocks.

Capacitance — A property of electric circuits which allows them to store an electric charge.

Capacitive Reactance — The opposition to current flow in an ac circuit by a capacitance, expressed in ohms.

Capacitor — A circuit element composed of two metallic plates separated by a dielectric, used to store electric charges temporarily.

Circuit — A conductor or group of conductors arranged so as to provide a continuous path to the flow of current.

Circuit Breaker — A device designed to protect electrical circuits from overloads by opening the circuit at preset limits. It can be reset after the cause of the overload is corrected.

Conductors — Materials which possess free electrons and allow a current to circulate when a voltage is applied to a closed circuit.

Core Losses — The total power required to heat the core of a transformer, composed of the power required to magnetize the core in alternate directions (hysteresis) and of the power dissipated by eddy currents flowing in the core.

Current — The flow of electrons through a conductor.

Cycle — A complete set of values (positive and negative) of an alternating current or voltage, occurring between two consecutive points.

Degree Day — A degree day (C) is registered when the average outside temperature for a day or 24 hour period is one degree C below 18 degrees C which represents the average inside temperature.

Delta Connection — An electrical connection which, on a conventional circuit diagram, has the shape of a triangle which resembles the Greek letter Δ.

Demand — The average value of power related to a given time interval.

Demand Control — The control, usually be electromechanical means, designed to limit or reduce the demand created by an electrical system.

Demand Meter — A meter which indicates or records the demand, maximum demand or both, usually in kW.

Direct Current — An electrical current which always flows in the same direction.

Dual Energy — A term used to designate systems which can use two forms of energy alternately or simultaneously.

Eddy Currents — Currents which flow in a mass of conducting material as a result of voltages induced by variations of the magnetic flux through the material.

Efficiency — The quotient of the Output divided by the Input to a device or machine.

Essential Loads — Electrical loads in a building or plant which must take precedence when limiting peak demand or in times of emergency.

Energy — The product of power over time.

Farads — The practical unit of capacitance.

Feeders — Conductors emanating from the distribution panel to supply electrical loads.

Fuses — A device designed to protect electrical circuits by providing the weakest link. A fuse is normally destroyed by an overload and must be replaced before the circuit can be reenergized.

Henry — The practical unit of inductance.

Hysteresis Losses — The energy required to magnetize a core when the magnetic flux changes direction.

Impedance — The total opposition to the flow of current in an alternating current circuit.

Inductance — The property of an electrical circuit by means of which it opposes any change of current.

Inductive Reactance — The opposition to current flow in an ac circuit by an inductance, expressed in ohms.

Insulators — Materials which have no free electrons and do not allow the current to flow easily.

Lagging Current — An alternating current which, in each half cycle, reaches its maximum value a fraction of a cycle later than the voltage which causes it to flow.

Leading Current — An alternating current which, in each half cycle, reaches its maximum value a fraction of a cycle sooner than the voltage which causes it to flow.

Load Factor — The ratio of average load over a given time period to the maximum demand during the period.

Maximum Demand — The highest demand (kW) measured over a given period of time.

Non-Essential Loads — Loads which can be deferred during electrical peaks or emergencies.

Peak Load — The maximum demand occurring in an electrical system during a given time period.

Power (true, active) — The product of the voltage and the current which is in phase with the voltage.

Power Factor — The ratio of true power to the apparent power.

Rate Structure — Full set of prices charged for different units of electricity consumed by a customer.

Reactive Power — The out-of-phase component of the total volt-amperes in an ac circuit. It includes both inductive and capacitive reactance.

Resistance — The opposition offered by a material to the flow of current. Expressed in ohms.

Resistivity — The specific resistance of a material. In the SI system, it is expressed in ohm meter at a given temperature.

Root-Mean-Square (rms) Value of Current or Voltage — The square root of the average square of the instantaneous values. Also called the effective value.

Semiconductors — Substances which are neither good conductors nor good insulators.

Service Entrance — The place where electricity enters a building or a plant.

Thermal Storage — The storing of thermal energy for later use. Can be used to reduce electrical demand.

Vars — The term used for volt-amperes reactive.

Volt — The unit of potential difference or electromotive force. One volt will cause one ampere to flow through a resistance of one ohm.

Voltmeter — An instrument to measure electrical energy.

Watt — A unit of power. It is the power expended when a current of one ampere flows through a resistance of one ohm.

Watthour — A unit of electrical energy. It is equal to the energy produced by one watt during one hour.

Wye Connection — An electrical connection which, on a conventional circuit diagram, resembles the letter Y. Sometime called the star connection.

Table 1

KW Multipliers to Determine Capacitor Kilovars Required For Power-Factor Corrections

	Corrected Power Factor																				
Original Power Factor	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00
0.50	0.982	1.006	1.034	1.060	1.086	1.112	1.139	1.166	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.440	1.481	1.529	1.589	1.732
0.51	0.937	0.962	0.969	1.015	1.041	1.067	1.094	1.120	1.147	1.175	1.203	1.231	1.261	1.292	1.324	1.358	1.395	1.436	1.484	1.544	1.687
0.52	0.893	0.919	0.945	0.971	0.997	1.023	1.050	1.076	1.103	1.131	1.159	1.187	1.217	1.248	1.280	1.314	1.351	1.392	1.440	1.500	1.643
0.53	0.850	0.876	0.902	0.928	0.954	0.980	1.007	1.033	1.060	1.068	1.116	1.144	1.174	1.205	1.237	1.271	1.306	1.349	1.397	1.457	1.600
0.54	0.809	0.835	0.861	0.887	0.913	0.939	0.966	0.992	1.019	1.047	1.075	1.103	1.133	1.164	1.196	1.230	1.267	1.308	1.358	1.418	1.559
0.55	0.769	0.795	0.821	0.847	0.873	0.899	0.926	0.952	0.979	1.007	1.035	1.063	1.093	1.124	1.158	1.190	1.227	1.268	1.318	1.376	1.519
0.56	0.730	0.756	0.782	0.806	0.834	0.850	0.887	0.913	0.940	0.963	0.996	1.024	1.054	1.065	1.117	1.151	1.188	1.229	1.277	1.337	1.480
0.57	0.692	0.718	0.744	0.770	0.796	0.822	0.849	0.875	0.902	0.930	0.958	0.988	1.016	1.047	1.079	1.113	1.150	1.191	1.239	1.299	1.442
0.58	0.655	0.681	0.707	0.733	0.750	0.785	0.812	0.838	0.865	0.893	0.921	0.949	0.979	1.010	1.042	1.076	1.113	1.154	1.202	1.262	1.405
0.59	0.619	0.645	0.671	0.697	0.723	0.749	0.776	0.802	0.829	0.857	0.885	0.913	0.943	0.974	1.006	1.040	1.077	1.118	1.168	1.226	1.369
0.60	0.583	0.609	0.635	0.661	0.687	0.713	0.740	0.766	0.793	0.821	0.849	0.877	0.907	0.935	0.970	1.004	1.041	1.062	1.130	1.190	1.333
0.61	0.549	0.575	0.601	0.627	0.653	0.679	0.705	0.732	0.759	0.787	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.156	1.299
0.62	0.516	0.542	0.568	0.594	0.620	0.648	0.673	0.699	0.726	0.754	0.782	0.810	0.840	0.871	0.903	0.937	0.974	1.015	1.063	1.123	1.266
0.63	0.483	0.509	0.535	0.561	0.587	0.613	0.640	0.656	0.693	0.721	0.749	0.777	0.807	0.836	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	0.451	0.474	0.503	0.529	0.555	0.581	0.605	0.634	0.661	0.689	0.717	0.745	0.775	0.804	0.838	0.872	0.909	0.905	0.998	1.068	1.201
0.65	0.419	0.445	0.471	0.497	0.523	0.549	0.576	0.602	0.629	0.657	0.685	0.713	0.743	0.774	0.806	0.840	0.877	0.918	0.968	1.026	1.189
0.66	0.388	0.414	0.440	0.486	0.492	0.518	0.545	0.571	0.596	0.628	0.654	0.682	0.712	0.743	0.775	0.809	0.846	0.887	0.935	0.995	1.138
0.67	0.358	0.384	0.410	0.436	0.462	0.488	0.515	0.541	0.568	0.596	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.965	1.108
0.68	0.328	0.354	0.380	0.408	0.432	0.458	0.485	0.511	0.538	0.566	0.594	0.622	0.652	0.683	0.715	0.749	0.766	0.827	0.875	0.935	1.078
0.69	0.299	0.325	0.351	0.377	0.403	0.429	0.456	0.482	0.509	0.537	0.565	0.593	0.623	0.654	0.688	0.720	0.757	0.798	0.846	0.906	1.040
0.70	0.270	0.296	0.322	0.348	0.374	0.400	0.427	0.453	0.480	0.508	0.536	0.564	0.594	0.625	0.657	0.691	0.728	0.769	0.817	0.877	1.020
0.71	0.242	0.268	0.294	0.320	0.348	0.372	0.399	0.425	0.452	0.480	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.72	0.214	0.240	0.266	0.292	0.318	0.344	0.371	0.397	0.424	0.452	0.480	0.508	0.538	0.569	0.601	0.636	0.672	0.713	0.761	0.821	0.964
0.73	0.188	0.212	0.238	0.264	0.290	0.318	0.343	0.369	0.396	0.424	0.452	0.480	0.510	0.541	0.573	0.607	0.644	0.685	0.733	0.793	0.936
0.74	0.159	0.185	0.211	0.237	0.263	0.289	0.316	0.342	0.369	0.397	0.425	0.453	0.483	0.514	0.548	0.580	0.617	0.658	0.706	0.766	0.909
0.75	0.132	0.158	0.194	0.210	0.236	0.262	0.289	0.315	0.342	0.370	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.105	0.131	0.157	0.163	0.209	0.235	0.262	0.288	0.315	0.343	0.371	0.399	0.429	0.460	0.492	0.526	0.563	0.604	0.652	0.712	0.855
0.77	0.079	0.105	0.131	0.157	0.163	0.209	0.236	0.262	0.289	0.317	0.345	0.373	0.403	0.434	0.466	0.500	0.537	0.578	0.626	0.665	0.829
0.78	0.052	0.078	0.104	0.130	0.154	0.182	0.209	0.235	0.262	0.290	0.318	0.346	0.376	0.407	0.439	0.473	0.510	0.551	0.599	0.659	0.802
0.79	0.026	0.052	0.078	0.104	0.130	0.156	0.183	0.209	0.236	0.264	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.633	0.776
0.80	0.000	0.026	0.052	0.076	0.104	0.130	0.157	0.183	0.210	0.238	0.264	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.609	0.750
0.81		0.000	0.026	0.052	0.076	0.104	0.131	0.157	0.184	0.212	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.681	0.724
0.82			0.000	0.028	0.052	0.078	0.105	0.131	0.158	0.166	0.214	0.242	0.272	0.303	0.335	0.389	0.406	0.447	0.495	0.555	0.698
0.83				0.000	0.026	0.052	0.062	0.079	0.105	0.132	0.160	0.188	0.216	0.246	0.277	0.309	0.343	0.421	0.469	0.529	0.672
0.84					0.000	0.026	0.053	0.079	0.106	0.134	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
0.85						0.000	0.027	0.053	0.080	0.108	0.136	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86							0.000	0.026	0.053	0.061	0.109	0.137	0.167	0.198	0.230	0.264	0.301	0.342	0.390	0.450	0.593
0.87								0.000	0.027	0.058	0.063	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88									0.000	0.028	0.056	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89										0.000	0.028	0.056	0.088	0.117	0.149	0.183	0.220	0.261	0.308	0.389	0.512
0.90											0.000	0.028	0.058	0.069	0.121	0.155	0.192	0.233	0.281	0.341	0.484
0.91												0.000	0.030	0.061	0.083	0.127	0.164	0.205	0.253	0.313	0.458
0.92													0.000	0.031	0.063	0.097	0.134	0.175	0.223	0.283	0.426
0.93														0.000	0.032	0.068	0.103	0.144	0.192	0.252	0.395
0.94															0.000	0.034	0.071	0.112	0.160	0.220	0.363
0.95																0.000	0.037	0.079	0.126	0.184	0.329
0.96																	0.000	0.041	0.069	0.149	0.292
0.97																		0.000	0.048	0.108	0.251
0.98																			0.000	0.060	0.203
0.99																				0.000	0.143

Table 2

STRANDED BARE COPPER AND ALUMINUM CONDUCTORS

CONDUCTOR SIZE		AREA		NO. OF WIRES*	WIRE DIAMETER		NOMINAL CONDUCTOR DIAMETER					
							Class 'B' Standard		Compressed Round		Compact Round	
AWG	Circ. Mils	mm²	sq.in		mm	in	mm	in	mm	in	mm	in
20	1020	0.519	.00080	7	0.31	.0121	.92	.036				
18	1620	0.823	.00128	7	0.39	.0152	1.16	.046				
16	2580	1.31	203	7	0.49	.0192	1.46	.058				
14	4110	2.08	323	7	0.61	.0242	1.84	.073	1.78	.072		
12	6530	3.31	513	7	0.77	.0305	2.32	.092	2.25	.090		
10	10380	5.26	816	7	0.98	.0385	2.95	.116	2.86	.114		
8	16510	8.37	.01297	7	1.23	.0486	3.71	.146	3.60	.143	3.40	.134
6	26240	13.30	2061	7	1.55	.0612	4.67	.184	4.53	.180	4.29	.169
4	41740	21.15	3278	7	1.96	.0772	5.89	.232	5.71	.226	5.41	.213
3	52620	26.66	4133	7	2.30	.0867	6.60	.260	6.40	.254	6.05	.238
2	66360	33.62	5212	7	2.47	.0974	7.42	.292	7.20	.285	6.87	.268
1	83690	42.41	6573	19(18)	1.69	.0664	8.43	332	8.18	.324	7.60	.299
1/0	105600	53.51	8291	19(18)	1.89	.0745	9.47	.373	9.19	.364	8.55	.336
2/0	133100	67.44	.1045	19(18)	2.13	.0837	10.64	.419	10.32	.407	9.57	.376
3/0	167800	85.02	.1318	19(18)	2.39	.0940	11.94	.470	11.58	.458	10.8	.423
4/0	211600	107.22	.1662	19(18)	2.68	.1055	13.41	.528	13.00	.514	12.1	.475
250 MCM		126.68	.1963	37(35)	2.09	.0822	14.60	.575	14.16	.561	13.2	.520
300		152.01	.2356	37(35)	2.31	.0900	16.00	.630	15.52	.614	14.5	.570
350		177.34	.2749	37(35)	2.47	.0973	17.30	.681	16.78	.664	15.7	.616
400		202.68	.3142	37(35)	2.64	.1040	18.49	.728	17.94	.709	16.7	.659
500		253.36	.3927	37(35)	2.95	.1162	20.65	.813	20.03	.792	18.7	.736
600		304.02	.4712	61(58)	2.52	.0992	22.68	.893	22.00	.870	20.7	.813
750		380.03	.5890	61(58)	2.82	.1109	25.35	.998	24.59	.972	23.0	.908
1000		506.70	.7854	61(58)	3.25	.1280	29.26	1.152	28.38	1.121	26.9	1.060
1250		633.38	9817	91	2.98	.1172	32.74	1.289	31.76	1.250		
1500		760.05	1.178	91	3.26	.1284	35.86	1.412	34.78	1.370		
1750		886.73	1.374	127	2.98	.1174	38.76	1.526	37.60	1.479		
2000		1013.40	1.571	127	3.19	.1255	41.45	1.632	40.21	1.583		

*Reduced number of wires for compact strandings are shown in parentheses.

The strand data and metric equivalents in this table are based where possible on EEMAC recommendations current at the time of compilation, otherwise on published ICEA standards.

canada wire

Table 3
Insulated Wire

Type of Insulation	No. of Conductors	Service–Characteristics	Voltage	Wire Sizes
Non–metallic Sheathed Cable (Nylon & PVC)	2 – 3 Copper	Open & Concealed Wiring, Wet or Dry Locations; Not exposed to Mechanical Injury	300 v.	2 – 14
PVC	1 Copper	Exposed Wiring Concealed Knob & Tube Wiring; Dry & Wet Locations	600 v.	14 – 500
Polyethylene	1 Copper Aluminum	Open Wiring & Raceways Dry & Wet Locations Exposed to Weather	600/ 1000 v.	14 –2000
Thick Polyethlyene	1 Copper Aluminum	Direct Earth Burial Exposed Wiring Service Entrance	1000 v.	14 –2000
PVC & Nylon	1 Copper	General Purpose Building Wire	600 v.	14 – 500
PVC	2–3 Copper	Submersible Pumps	600 v.	14 –410
Armoured Cable (Aluminum or Steel Armour) + Polyethlyene	2–3–4 Copper or Aluminum	Open & Concealed Wiring; Dry Locations	600 / 1000 v.	14 –1000
Armoured Cable with Polyethlyene Covering	1 Multi Copper or Aluminum	Exposed, Concealed Wet & Dry Locations Direct Burial	600 / 1000v.	14 –100

Note: When contemplating replacing a given conductor with a substitute, the installer should obtain the approval of local authorities having jurisdiction over the application of the Canadian Electrical Code.

Table 4
Approximate Comparison of Transformer Options

TYPE	LIQUID				DRY						
Number	1	2	3	4	5	6	7	8	9	10	11
					Ventilated Standard "Open Coil"					Non-Ventilated	
Description	Oil	Silicone	R-Temp	Vapour Cond	Class 220	Class 185	Class 150	Vacuum Impreg. Epoxy	Cast Epoxy	Non-Vent. "Open Coil"	Sealed Gas Fitted
Relative Price %											
5 & 15 kV	100*	140*	130*	?	90	110	120	130	200	160	200
25 kV**	100*	140*	130*		130	—	—	140	210	170	210
Relative Size											
5 & 15 kV	1.00	1.00	1.15	.95	0.90	1.05	1.10	1.05	1.05	1.60	1.60
25 kV**	1.00	1.05	1.15	.96	1.10	1.15	1.20	1.15	1.10	1.80	1.80
Relative Losses											
5 & 15 kV	1.00	1.00	1.00	?	1.30	1.15	1.05	1.15	1.10	1.05	1.05
Performance											
Humidity	E	E	E	E	G	G	G	G	G	G	E
Moisture	E	E	E	E	P	P	P	P	P	G	E
Dirt	G	G	G	G	P	P	P	P	P	G	E
Conductive Dust	E	E	E	E	N	N	N	N	N	P	E
Rough Handling	G	G	G	G	P	P	P	G	G	P	E

NOTES:
* = Add Cost of Structure
** = Assume 25 kV Dry, 125 kV Bil

CODES: E = Excellent
G = Good
P = Poor

Table 5
Overall Comparison of Lamp Types

Type	Lumens/Watt (range)	Lamp Life Hours	Service–Characteristics
Incandescent	15 – 20	1,200 / 1,500	All Wattages, Inefficient, Some Aesthetic Unity p.f.
Fluorescent	50 – 75	20,000 / 38,000	Wide Selection, Medium Efficiency, p.f. Function of Quality
Mercury Vapor (H.I.D.)	25 – 65	20,000 / 24,000	Being Replaced by Other HID Types, Medium Efficiency
Metal Halide (H.I.D.)	80 – 125	7,500 / 20,000	Many Applications, Efficient, Lamp of the Future
High Pressure Sodium (H.I.D.)	95 – 140	24,000	Small Size, Good Optical Control, Good Colour, Lamp of the Future
Low Pressure Sodium	135 – 180	24,000	Highest Efficiency, Poor Light Quality, Some Outdoor Applications

Note: H.I.D. = High intensity discharge lamps. In these lamps, light is produced in an arc tube by a current at relatively high pressue compared to the pressure in a fluorescent tube.

Table 6
Electric Heaters

Type	Service–Characteristics	Relative Cost
Insertion	Heating of liquids, direct heat transfer	M
Circulation	Heating of liquids & gases, quick response	M
Process air	Air heating, flexible	L
Radiant	Comfort & process, fast, versatile	M
Process	Strip, tubular, cartridge, ring, disc, cast–in, specialized applications	L & M
Cable	Tracing, pipe heating	L
Explosion proof	Hazardous locations, safe	H
Miscellaneous	Melting pots, hotplates & ovens	L & M

LEGEND:
L = LOW COST
M = MEDIUM COST
H = HIGH COST

COMMON CONVERSIONS

1 barrel (35 Imp gal) (42 US gal) = 159.1 litres

1 gallon (Imp) = 1.20094 gallon (US)

1 horsepower (boiler) = 9809.6 watts

1 horsepower = 2545 Btu/hour

1 horsepower = 0.746 kilowatts

1 joule = 1 N-m

Kelvin = (°C + 273.15)

1 kilowatt-hour = 3600 kilojoules

1 Newton = 1 kg-m/s^2

1 therm = 10^5 Btu

1 ton (refrigerant) = 12002.84 Btu/hour

1 ton (refrigerant) = 3516.8 watts

1 watt = 1 joule/second

Rankine = (°F + 459.67)

Cubes

1 yd^3 = 27 ft^3

1 ft^3 = 1728 in^3

1 cm^3 = 1000 mm^3

1 m^3 = 10^6 cm^3

1 m^3 = 1000 L

Squares

1 yd^2 = 9 ft^2

1 ft^2 = 144 in^2

1 cm^2 = 100 mm^2

1 m^2 = 10000 cm^2

SI PREFIXES

Prefix	Symbol	Magnitude	Factor
tera	T	1 000 000 000 000	10^{12}
giga	G	1 000 000 000	10^{9}
mega	M	1 000 000	10^{6}
kilo	k	1 000	10^{3}
hecto	h	100	10^{2}
deca	da	10	10^{1}
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	u	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
pica	p	0.000 000 000 001	10^{-12}

UNIT CONVERSION TABLES
METRIC TO IMPERIAL

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
amperes/square centimetre	A/cm^2	amperes/square inch	A/in^2	6.452
Celsius	°C	Fahrenheit	°F	(°C × 9/5) + 32
centimetres	cm	inches	in	0.3937
cubic centimetres	cm^3	cubic inches	in^3	0.06102
cubic metres	m^3	cubic foot	ft^3	35.314
grams	g	ounces	oz	0.03527
grams	g	pounds	lb	0.0022
grams/litre	g/L	pounds/cubic foot	lb/ft^3	0.06243
joules	J	Btu	Btu	9.480×10^{-4}
joules	J	foot-pounds	ft-lb	0.7376
joules	J	horsepower-hours	hp-h	3.73×10^{-7}
joules/metre, (Newtons)	J/m, N	pounds	lb	0.2248
kilograms	kg	pounds	lb	2.205
kilograms	kg	tons (long)	ton	9.842×10^{-4}
kilograms	kg	tons (short)	tn	1.102×10^{-3}
kilometres	km	miles (statute)	mi	0.6214
kilopascals	kPa	atmospheres	atm	9.87×10^{-3}
kilopascals	kPa	inches of mercury (@ 32°F)	in Hg	0.2953
kilopascals	kPa	inches of water (@ 4°C)	in H_2O	4.0147
kilopascals	kPa	pounds/square inch	psi	0.1450
kilowatts	kW	foot-pounds/second	ft-lb/s	737.6
kilowatts	kW	horsepower	hp	1.341
kilowatt-hours	kWh	Btu	Btu	3413
litres	L	cubic foot	ft^3	0.03531
litres	L	gallons (Imp)	gal (Imp)	0.21998
litres	L	gallons (US)	gal (US)	0.2642
litres/second	L/s	cubic foot/minute	cfm	2.1186
lumen/square metre	lm/m^2	lumen/square foot	lm/ft^2	0.09290
lux, lumen/square metre	lx, lm/m^2	footcandles	fc	0.09290
metres	m	foot	ft	3.281
metres	m	yard	yd	1.09361
parts per million	ppm	grains/gallon (Imp)	gr/gal (Imp)	0.07
parts per million	ppm	grains/gallon (US)	gr/gal (US)	0.05842
permeance (metric)	PERM	permeance (Imp)	perm	0.01748
square centimetres	cm^2	square inches	in^2	0.1550
square metres	m^2	square foot	ft^2	10.764
square metres	m^2	square yards	yd^2	1.196
tonne (metric)	t	pounds	lb	2204.6
watt	W	Btu/hour	Btu/h	3.413
watt	W	lumen	lm	668.45

UNIT CONVERSION TABLES
IMPERIAL TO METRIC

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
ampere/in^2	A/in^2	ampere/cm^2	A/cm^2	0.1550
atmospheres	atm	kilopascals	kPa	101.325
British Thermal Unit	Btu	joules	J	1054.8
Btu	Btu	kilogram-metre	kg-m	107.56
Btu	Btu	kilowatt-hour	kWh	2.928×10^{-4}
Btu/hour	Btu/h	watt	W	0.2931
calorie, gram	cal or g-cal	joules	J	4.186
chain	chain	metre	m	20.11684
cubic foot	ft^3	cubic metre	m^3	0.02832
cubic foot	ft^3	litre	L	28.32
cubic foot/minute	cfm	litre/second	L/s	0.47195
cycle/second	c/s	Hertz	Hz	1.00
Fahrenheit	°F	Celsius	°C	(°F-32)/1.8
foot	ft	metre	m	0.3048
footcandle	fc	lux, lumen/ square metre	lx, lm/m^2	10.764
footlambert	fL	candela/square metre	cd/m^2	3.42626
foot-pounds	ft-lb	joule	J	1.356
foot-pounds	ft-lb	kilogram-metres	kg-m	0.1383
foot-pounds/second	ft-lb/s	kilowatt	kW	1.356×10^{-3}
gallons (Imp)	gal (Imp)	litres	L	4.546
gallons (US)	gal (US)	litres	L	3.785
grains/gallon (Imp)	gr/gal (Imp)	parts per million	ppm	14.286
grains/gallon (US)	gr/gal (US)	parts per million	ppm	17.118
horsepower	hp	watts	W	745.7
horsepower-hours	hp-h	joules	J	2.684×10^6
inches	in	centimetres	cm	2.540
inches of Mercury (@ 32°F)	in Hg	kilopascals	kPa	3.386
inches of water (@ 4°C)	in H_2O	kilopascals	kPa	0.2491

UNIT CONVERSION TABLES
IMPERIAL TO METRIC (cont'd)

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
lamberts	* L	candela/square metre	cd/m^2	3.183
lumen/square foot	lm/ft^2	lumen/square metre	lm/m^2	10.76
lumen	lm	watt	W	0.001496
miles (statute)	mi	kilometres	km	1.6093
ounces	oz	grams	g	28.35
perm (at 0°C)	perm	kilogram per pascal-second-square metre	kg/Pa-s-m^2 (PERM)	5.721×10^{-11}
perm (at 23°C)	perm	kilogram per pascal-second-square metre	kg/Pa-s-m^2 (PERM)	5.745×10^{-11}
perm-inch (at 0°C)	perm. in.	kilogram per pascal-second-metre	kg/Pa-s-m	1.4532×10^{-12}
perm-inch (at 23°C)	perm. in.	kilogram per pascal-second-metre	kg/Pa-s-m	1.4593×10^{-12}
pint (Imp)	pt	litre	L	0.56826
pounds	lb	grams	g	453.5924
pounds	lb	joules/metre, (Newtons)	J/m, N	4.448
pounds	lb	kilograms	kg	0.4536
pounds	lb	tonne (metric)	t	4.536×10^{-4}
pounds/cubic foot	lb/ft^3	grams/litre	g/L	16.02
pounds/square inch	psi	kilopascals	kPa	6.89476
quarts	qt	litres	L	1.1365
slug	slug	kilograms	kg	14.5939
square foot	ft^2	square metre	m^2	0.09290
square inches	in^2	square centimetres	cm^2	6.452
square yards	yd^2	square metres	m^2	0.83613
tons (long)	ton	kilograms	kg	1016
tons (short)	tn	kilograms	kg	907.185
yards	yd	metres	m	0.9144

* "L" as used in Lighting

4138T/T33(-2)

The following typical values for conversion factors may be used when actual data are unavailable. The MJ and Btu equivalencies are heats of combustion. Hydrocarbons are shown at the higher heating value, wet basis. Some items listed are typically feedstocks, but are included for completeness and as a reference source. The conversion factors for coal are approximate since the heating value of a specific coal is dependent on the particular mine from which it is obtained.

ENERGY TYPE	METRIC	IMPERIAL
COAL		
— metallurgical	29,000 megajoules/tonne	25.0 × 10^6 Btu/ton
— anthracite	30,000 megajoules/tonne	25.8 × 10^6 Btu/ton
— bituminous	32,100 megajoules/tonne	27.6 × 10^6 Btu/ton
— sub-bituminous	22,100 megajoules/tonne	19.0 × 10^6 Btu/ton
— lignite	16,700 megajoules/tonne	14.4 × 10^6 Btu/ton
COKE		
— metallurgical	30,200 megajoules/tonne	26.0 × 10^6 Btu/ton
— petroleum		
— raw	23,300 megajoules/tonne	20.0 × 10^6 Btu/ton
— calcined	32,600 megajoules/tonne	28.0 × 10^6 Btu/ton
PITCH	37,200 megajoules/tonne	32.0 × 10^6 Btu/ton
CRUDE OIL	38,5 megajoules/litre	5.8 × 10^6 Btu/bbl
No. 2 OIL	38.68 megajoules/litre	5.88 × 10^6 Btu/bbl
		.168 × 10^6 Btu/IG
No. 4 OIL	40.1 megajoules/litre	6.04 × 10^6 Btu/bbl
		.173 × 10^6 Btu/IG
No. 6 OIL (RESID. BUNKER C)		
@ 2.5% sulphur	42.3 megajoules/litre	6.38 × 10^6 Btu/bbl
		.182 × 10^6 Btu/IG
@ 1.0% sulphur	40.5 megajoules/litre	6.11 × 10^6 Btu/bbl
		.174 × 10^6 Btu/IG
@ .5% sulphur	40.2 megajoules/litre	6.05 × 10^6 Btu/bbl
		.173 × 10^6 Btu/IG
KEROSENE	37.68 megajoules/litre	.167 × 10^6 Btu/IG
DIESEL FUEL	38.68 megajoules/litre	.172 × 10^6 Btu/IG
GASOLINE	36.2 megajoules/litre	.156 × 10^6 Btu/IG
NATURAL GAS	37.2 megajoules/m^3	1.00 × 10^6 Btu/MCF
PROPANE	50.3 megajoules/kg	.02165 × 10^6 Btu/lb
	26.6 megajoules/litre	.1145 × 10^6 Btu/IG
ELECTRICITY	3.6 megajoules/kWh	.003413 × 10^6 Btu/kWh

Electricity Cost Data
Section: Housekeeping
Worksheet #1

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Month	kWh	kW Demand		KVA	$Cost		Degree Days
		Act.	Bil.		Tot.	Per Unit	
Jan.							
Feb.							
Mar.							
April							
[illegible]y							
June							
July							
Aug.							
Sept.							
Oct.							
Nov.							
[illegible]c.							
Total							

Section: Housekeeping
Worksheet #2

Shutdown Checklist

Equipment **Time of Shutdown**

am pm am
8–9–10–11–12–1–2–3–4–5–6–7–8–9–10–11–12–1–2–3–4–5–6–7

Plant Area #1
Compressors
Lights
Other
Plant Area #2
Maintenance Shops
Pumps
Lights
Other
Office Area #1
Displays
Lights
Other
Office Area #2
Laboratories
Lights
Appliances
Other
Warehouse
Light
Exterior Lights
Parking #1
Parking #2
Yard lights
Floodlights

Rescheduling of Activities
Section : Housekeeping
Worksheet # 3

Company : ______________________ Date : ____________

Location : ______________________ By : ____________

Load Profile Analysis

Peak Period or Periods : ____________

Peak kW : ____________

Type	kW	kW	Rescheduling Possibilities Comments

Total kW : ________

Total Possible Reduction : ________ kW

Cost of Peak kW per Month : ________

Estimated Monthly Savings ($) : kW x Cost $ / Month = ____________

____________ = ____________

Power Factor Correction
Section : Retrofit
Worksheet #4

Company : ______________________________ Date : ________________

Location : ______________________________ By : ________________

kVA Reading (during billing period) : ________________ kVA

kW Reading (during billing period) : ________________ kW

Actual Consumption : kW x Overall Multiplier

________________ = ________________

Actual Consumption : kVA x Overall Multiplier :

________________ = ________________

Present Power Factor = kW / kVA = ________________ = ________________

Desired p.f. = ________________

Using table 1 : (kW multiplier) ;

To correct from p.f. ____________ to ____________ p.f. = ____________

Capacitor Requirements : kW x Multiplier (Table 1) =

________________ = ________________

Monthly Savings :

Billed Demand (highest of)

Actual Monthly Peak kW = ________________

Actual Monthly Peak kVA x p.f. (in rate) = ________________

Other kW (such as ratchet) = ________________

Corrected Demand = ________________

kW Savings = Billed Demand – Corrected Demand =

____

$ Savings at $ / kW = ________________ = ________________

Or Savings = Previous Monthly Bill – Bill after p.f. corr. = ________________

Yearly Savings = ________________ = ________________

Simple Payback : $\frac{\text{Cost of Capacitors}}{\text{Yearly Savings}}$: ________________ = ________________

Motor Power Factor Correction
Section : Retrofit
Worksheet #5

Company : ______________________ Date : ______________

Location : ______________________ By : ______________

Motor Data : Serial Number : ______________

Input kW : _____ x _____ : _____ x _____ = _________ kW

Input kVA : _____ x _____ x _____ : _____ x _____ x _____ = _________ kVA

Power Factor : _________ : _________ = _________ = p.f

Desired Power Factor _________________ = p.f.

Using table 1 : (kW multiplier) : _________________

To correct from p.f. _________ to _________ p.f. = _________

Capacitor Requirements : kW x Multiplier (Table 1) =

_______________ = _______________

Monthly Savings :

Billed Demand (highest of)

Actual Monthly Peak kW = _____________

Actual Monthly Peak kVA x p.f. (in rate) = _____________

Other kW (such as ratchet) = _____________

____

Corrected Demand = _____________

kW Savings = Billed Demand – Corrected Demand =

____

$ Savings at $ / kW = _____________ = _____________

Or Savings = Previous Monthly Bill – Bill after p.f. corr. =

Yearly Savings = _____________ = _____________

Simple Payback : $\frac{\text{Cost of Capacitors}}{\text{Yearly Savings}}$: _____________ = _____________

Electrical Load Management
Section : Retrofit
Worksheet #6

Company : ______________________ Date : ______________

Location : ______________________ By : ______________

List of Essential Loads :

Load	Operating Period		kW Rating
	Peak	Non–Peak	
Total Essential Loads :			

List of Non–Essential Loads :

Load	Operating Period		kW Rating
	Peak	Non–Peak	

Actual Peak Demand as Billed by Utility: ______________ kW

Potential (kW) for Peak Shaving:

Peak Demand as Billed – Total Essential Loads (kW)

______________________ (kW)

Estimated Savings : Potential (kW) x Cost / kW / month

____

Estimated $ Cost of Peak Reduction : ___________ $

First Estimate of Payback Period $\frac{\text{Cost}}{\text{Savings x 12}}$: Years

______________ = ______________ Years

Energy Efficient Motors
Section : Retrofit
Worksheet # 7

Company : ____________________ Date : ____________

Location : ____________________ By : ____________

Motor Data : Serial Number : ____________

Motor hp from Nameplate Data : ____________ hp (1)

Average Yearly Energy Cost per kWh (from cost data worksheet) : ____________ $/kWh (2)

Efficiency of Present Motor (measured or from nameplate) : ____________ % (3)

Efficiency of New Motor (from manufacturer) : ____________ % (4)

Premium Cost of New e.e. Motor : ____________ % (5)

Number of Hours of Operation per Year : ____________ hr/yr (6)

Measured Motor Loading : ____________ % (7)

Savings / Year

$$\frac{\text{hp} \times 0.0746 \times \%\,\text{load} \times \text{Avg. Energy Cost} \times \text{hrs}}{100 \qquad\qquad \text{year}} \times \left(\frac{1}{3} - \frac{1}{4}\right):$$

$$\frac{(1) \times 0.746 \times (7) \times (2) \times (6)}{100} \times \left(\frac{1}{(3)} - \frac{1}{(4)}\right) (8):$$

Savings : ____________________ = ____________

Simple Payback : Cost / Savings : (5) / (8)

____________________ = ____________

Legend : p.e. = Present Motor Efficiency
n.e. = New Motor Efficiency

Energy Efficient Transformers
Section : Retrofit
Worksheet # 8

Company : ______________________________ Date : ______________

Location : ______________________________ By : ______________

Transformer Serial Number : ________________

Transformer Rating (kW) : ____________ kW (1)

Average Yearly Energy Cost per kWh (from cost data worksheet) : ____________ $/kWh (2)

Efficiency of Present Transformer (measured or from nameplate) : ____________ % (3)

Efficiency of New Transformer (from manufacturer) : ____________ % (4)

Premium Cost of New e.e Transformer : ____________ $ (5)

Number of Hours of Operation per Year : ____________ hrs/yr (6)

Measured Transformer Loading : ____________ % (7)

Savings / Year :

$$\frac{\text{kW} \times \text{\% load} \times \text{Avg. Energy Cost} \times \text{hrs}}{100 \qquad\qquad \text{year}} \times \left(\frac{1}{\text{p.e.}} - \frac{1}{\text{n.e.}}\right) :$$

$$\frac{(1) \times (7) \times (2) \times (6)}{100} \times \left(\frac{1}{(3)} - \frac{1}{(4)}\right) : \qquad (8)$$

Savings : ______________________________ = ____________

Simple Payback : Cost / Savings : (5) / (8)

________________ = ____________

Legend :
p.e. = Present Transformer Efficiency
n.e. = New Transformer Efficiency