ENERGY MEASUREMENT

Energy can be defined as the capacity to do work, while power can be defined as the rate of doing work. There are different types of energy, including electrical energy, heat energy, nuclear energy, and solar energy. Energy may be converted from one form to another; for instance, electricity is often generated in power plants by converting hydraulic or fuel energy into electrical energy. Most vehicles are driven using energy derived from hydrocarbon fuels, and cooking is often done using electrical energy. Figure 1 shows the rapid increase of energy consumption in recent decades which helps us to get an idea of our ever increasing dependence on energy. Therefore, energy measurement becomes an extremely important topic for scientists and engineers. In this article, we will deal with different aspects of electrical energy measurement. Generally speaking, the measurement of energy is essentially the same as the measurement of power, except that the instrument must not merely indicate the power, but must take into account the length of time for which this power supply is maintained (1). Energy meters can be broadly classified into (1) electrolytic meters, (2) clock meters, (3) motor meters, and (4) electronic or microprocessor-based meters.

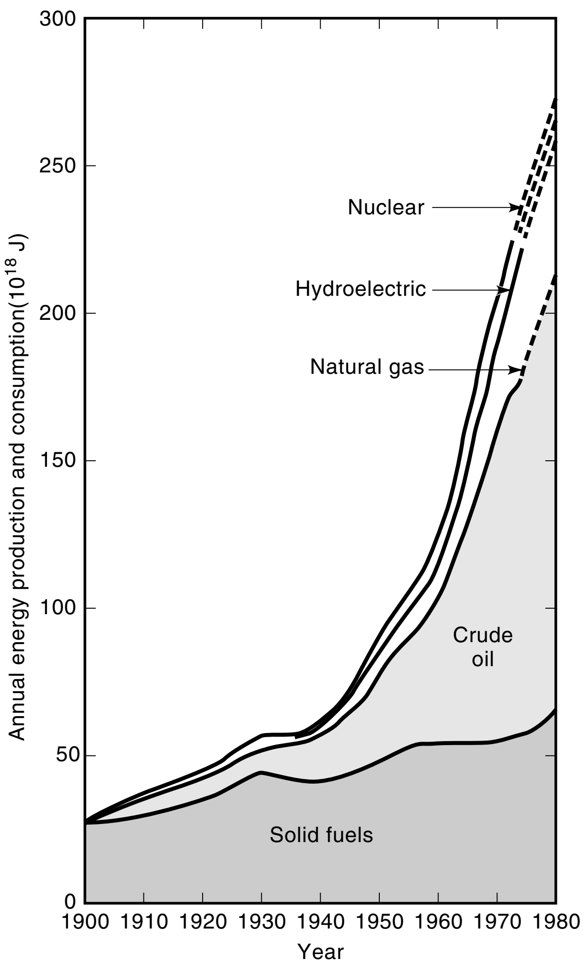

Figure 1. Graph depicting our increasing dependence on energy.

THEORY

Before discussing energy measurement itself, let us mathematically define electrical energy with respect to power. This will help us to understand energy measurement in greater detail. In this context it is desirable to consider alternating current (ac) and direct current (dc). Alternating current varies in magnitude and direction with time. However, dc current remains constant with time. Now, dc power (P) is defined as the product of voltage and current, that is,

$$P = VI \tag{1}$$

where V is the dc voltage in volts and I is the dc current in amperes. The direction of positive current flow is defined to be the direction a positive charge flows (or would flow if possible), and positive power is delivered when positive current flows from a point of higher voltage or potential to a point of lower voltage. Since V or I may be either positive or negative, power may itself be positive or negative. Positive power implies power delivered to a device or load, while negative power implies that power has been generated, that is, converted from some other form to electrical. Electrical power is typically expressed in watts.

In many systems the voltage and current are proportional, and are related by Ohm's law, $V = IR$, where R is the load resistance in ohms. Using Ohm's law, Eq. (1) may be rewritten as

$$P = I^2R \tag{2}$$

If the voltage and current vary with time, the instantaneous power (p) is defined as

$$p = vi \tag{3}$$

where v is the instantaneous voltage and i is the instantaneous current. Typically power is distributed to consumers in sinusoidal form, so that both the voltage and current are assumed to be sinusoidal and have the same frequency. An important measure of power, especially for periodic voltages and currents, is called average power. The average power is equal to the average rate at which energy is absorbed by an element, and it is independent of time (2). This is the power monitored by the electric utility company in determining monthly electricity bills. The average power (P_a) associated with a periodic instantaneous power signal is given by

$$P_a = \frac{1}{T_p}\int_{t_0}^{t_0+T_p} p\,dt = \frac{1}{T_p}\int_{t_0}^{t_0+T_p} vi\,dt \tag{4}$$

where T_p is the period of both v and i, and t_0 is arbitrary. If the effective or root mean square (rms) values of the instantaneous voltage v and instantaneous current i are denoted by $|V|$ and $|I|$, and the phase angles of the voltage and current are θ_v and θ_i, then the average power delivered to the load is

$$P_a = |V|\,|I| \cos\theta \tag{5}$$

where $\theta = \theta_v - \theta_i$ is the phase difference between v and i. The factor $\cos\theta$ is called the power factor, and θ is the power factor angle. P_a is called real power, which implies that the power has transformed from electrical to nonelectrical form such as radiant, chemical, or mechanical. If the load is purely resistive, the voltage and current signals are in phase, and the average power becomes $P_a = |V|\,|I|$. The average power associated with purely inductive or capacitive circuits is zero, since power delivered to the inductor or capacitor during part of the cycle is returned during another part of the cycle. The power factor is zero, since the phase angle is 90°. In this case, the power is purely reactive. The reactive power (Q) is defined as

$$Q = |V|\,|I| \sin\theta \tag{6}$$

where the factor $\sin\theta$ is called the reactive factor. Reactive power is expressed in vars (volt-amperes reactive).

Energy is defined as the total work done over an interval of time (T), and the basic unit of energy is called the joule or watt-second. In many instances, this unit is inconvenient to use and larger units such as kilowatt-hour are used. Using Eq. (2), the dc energy can be expressed as

$$E_d = I^2RT \tag{7}$$

Using Eq. (5), the total energy delivered during time interval T can be expressed as

$$E_a = |V|\,|I| T \cos\theta \tag{8}$$

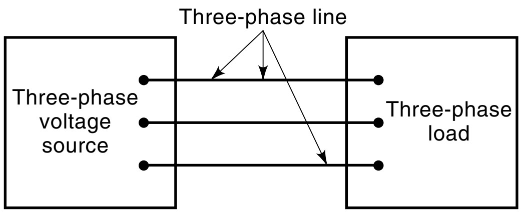

Figure 2. A basic three-phase circuit.

Similarly, using Eq. (6), the reactive energy can be expressed as

$$E_r = |V|\,|I|T \sin\theta \tag{9}$$

The generation, transmission, distribution, and utilization of large amount of electric energy are accomplished by means of three-phase circuits. A comprehensive analysis of three-phase circuits is beyond the scope of this article; a general understanding of balanced three-phase circuits is sufficient for our purpose. The basic structure of a three-phase system consists of voltage sources connected to the loads by means of transformers and transmission lines. Figure 2 shows the simplified block diagram of a basic three-phase circuit. A set of balanced three-phase voltages consists of three sinusoidal voltages that have identical amplitudes and frequency but are out of phase with each other by exactly 120°. In three-phase circuits the standard practice is to refer to the three phases as A, B, and C. Furthermore, phase A is almost always used as the reference phase. Because the phase voltages are out of phase by 120° the following two possible relationships can exist between the voltages:

First Possibility. $V_A = V_m\angle 0°$, $V_B = V_m\angle -120°$, $V_C = V_m\angle +120°$

Second Possibility. $V_A = V_m\angle 0°$, $V_B = V_m\angle +120°$, $V_C = V_m\angle -120°$

Here V_m represents the peak amplitude of the sinusoidal voltage. The energy delivered by a three-phase source and consumed by a three-phase load is found simply by adding the energies in the three phases. In a balanced three-phase circuit, however, this is the same as multiplying the average energy in any one phase by 3, since the average energy is same in all phases. Thus for a balanced three-phase circuit the active energy or energy may be expressed as

$$E_a = 3V_pI_pT \cos\theta_p \tag{10}$$

where V_p represents the magnitude of the phase voltage, I_p represents the magnitude of the phase current, and θ_p represents the phase difference between V_p and I_p. Similarly, the total reactive energy can be expressed as

$$E_r = 3V_pI_pT \sin\theta_p \tag{11}$$

In the case of energy the measuring instrument is called a watt–hour meter, while in the case of reactive energy the measuring instrument is called a reactive volt-ampere-hour meter.

WATT–HOUR METERS

A meter that records energy in watt-hours or kilowatt-hours is called a watt–hour meter. An important requirement of an energy meter is that it should indicate a given amount of energy proportional to power and time. For example, it should record 1 kW · h, whether this consists of 1 W flowing for 1000 h or 1000 W flowing for 1 h. Different types of watt–hour meters have been developed in the last few decades for the measurement of energy. We shall briefly discuss only those that are relevant today.

Electrolytic Watt–Hour Meters

Figure 3 shows an electrolytic watt–hour meter. This type of meter is mainly used for dc energy measurement, although it can be adapted, by using a metal rectifier circuit and a cur-

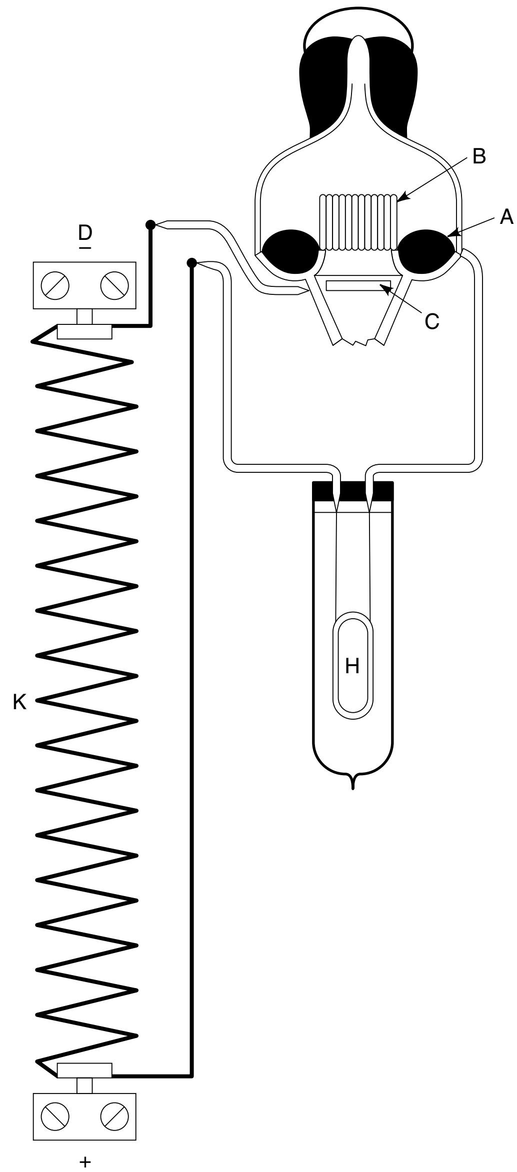

Figure 3. Electrolytic watt–hour meter. A, anode mercury; B, glass fence; C, cathode; D, negative terminal; E, positive terminal; K, shunt; H, compensating resistance in series with tube.

rent transformer, to function as an ac circuit for measuring kilovolt-ampere-hours. The operating current is passed through a solution, causing electrolytic action. Depending on the meter type, this gives a deposit of mercury or liberates gas proportional to the number of coulombs or ampere-hours passed through the meter. Assuming the voltage supply to the meter remains constant, the meter can be calibrated in kilowatt-hours; otherwise it is calibrated in ampere-hours. These meters are inexpensive to manufacture, but tend to require fairly frequent inspection, as they include a large amount of glass in their construction.

Clock Watt–Hour Meters

Figure 4 shows a clock watt–hour meter. There are two identical circular coils (C1 and C2), placed at the bottom ends of two pendulums, which are continuously driven by clockwork. These coils are connected in series with one another and with a high resistance, and they carry a current proportional to the line voltage. There are two current coils (C3 and C4), placed beneath the pendulums, which are connected in series with the line and are wound in such a way that their magnetic fields are in the opposite directions. When no current is flowing, the pendulums swing at the same rate. However, when current flows through C3 and C4, one of these coils exerts an accelerating force on one pendulum and the other coil exerts a retarding force on the other pendulum. The resulting difference in the time period of oscillation of two pendulums is arranged to give an indication on the dial register proportional to the energy passing through the meter. This meter is comparatively free from temperature errors and stray fields and is suitable for both ac and dc energy measurements.

Motor Watt–Hour Meters

Motor watt–hour meters can be broadly divided into two categories: those for dc and for ac energy measurement. The latter—also called induction watthour meters—can be further classified into single-phase and polyphase watt–hour meters.

Motor Watt–Hour Meter for dc Energy Measurement. A motor meter for dc energy measurement essentially consists of a small motor that is provided with a magnetic braking mechanism as shown in Fig. 5. The field coils of this meter consist of a few turns of heavy copper wire carrying the current under measurement, so that the field strength is directly proportional to the load current. Motor meters for dc energy measurement consist of three main parts—a rotating element, a braking system, and a clock or dial register. The rotating element is driven at a speed proportional to the energy or in some cases the quantity of electricity passing through the driving system. Proportionality between the energy and speed is ensured by the braking system, which supplies a controlling action proportional to the speed of the rotor element.

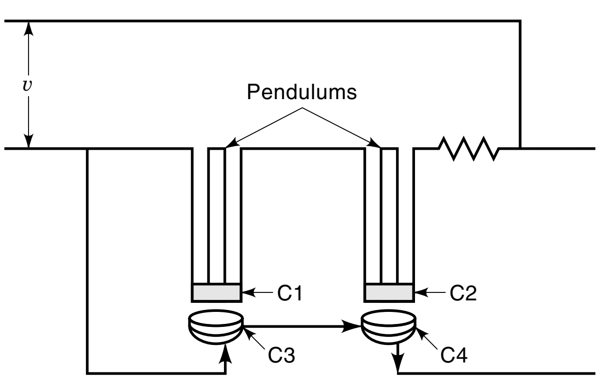

Figure 4. Clock watt–hour meter.

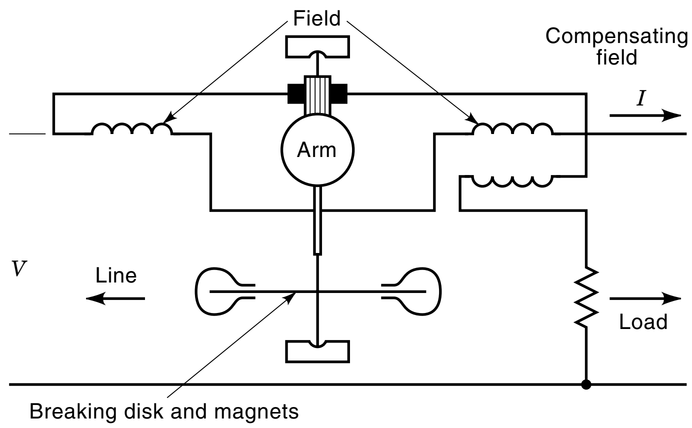

Figure 5. Motor watt–hour meter for dc energy measurement.

Single-Phase Induction Watt–Hour Meter. Induction meters are almost universally used for ac energy measurement, since they are simple in construction, provide high torque-to-weight ratio, and are relatively inexpensive. An induction watt–hour meter consists of an induction motor whose output is largely absorbed by the braking disk and dissipated as heat as shown in Fig. 6. In this watt–hour meter there are two current poles (2 and 4), which are displaced from the voltage pole (3) as shown in Fig. 6(a). At unity power factor, the flux ϕ_i from the current coils is in phase both with the voltage v and current i. The flux from the voltage coil, ϕ_v, is in quadrature (90° phase displacement) with respect to ϕ_i, as shown in Fig. 6(b). At time instant a, both the current i and current flux ϕ_i are maximum, the voltage v is maximum, and the voltage flux ϕ_v is minimum. The flux paths through the disk are from 2 to 1, from 2 to 3, from 3 to 4, and from 5 to 4. At time instant b, both the current i and current flux ϕ_i are minimum, but the voltage v is minimum and the voltage flux ϕ_v is maximum. At time instant c, both the current i and current flux ϕ_i are maximum, but the voltage v is maximum and the voltage flux ϕ_v is minimum. The flux paths through the disk are from 1 to 2, from 3 to 2, from 4 to 3, and from 4 to 5. Thus the flux has effectively moved across the disk from left to right. This change causes eddy currents to be set up in the disk. The reaction between the eddy currents and the field tends to move the disk in the direction of the field.

Since the disk revolves continuously when on load, electromagnetic forces (emfs) will be induced in it dynamically, as it cuts through the flux between the poles, in addition to the statically induced emfs due to the alternating flux in these poles. The torque due to the dynamically induced eddy currents in the disk will be negligible compared to the operating

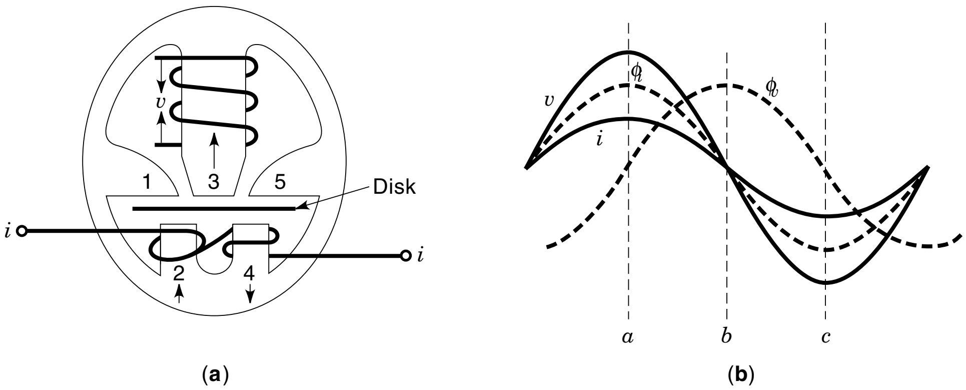

Figure 6. Induction watt–hour meter for ac energy measurement.

torque produced by the statically induced currents. Neglecting the effect of friction in the meter, and assuming that the active flux from the voltage pole lags 90° behind the impressed voltage, the operating or driving torque T_d becomes proportional to the power in the circuit, i.e.,

$$T_{\mathrm{d}} \propto |V|\,|I| \cos\theta \tag{12}$$

Now the retarding torque T_r due to eddy currents is proportional to the speed of revolution, N, of the disk, i.e., $T_r \propto N$. Since for a steady speed of the disk, T_d must be equal to T_r, we can write

$$N \propto |V|\,|I| \cos\theta \tag{13}$$

i.e., the speed of revolution of the disk is proportional to the power. The total number of revolutions, N_T, over a time interval T may be expressed as

$$N_{\mathrm{T}} = NT = |V|\,|I| T \cos\theta \tag{14}$$

From Eq. (14), it is evident that the total number of revolutions is proportional to the total energy supplied.

Polyphase Induction Watt–Hour Meter. Polyphase energy can be measured by several single-phase instruments, since the total power or energy is the sum of the readings of all the instruments. The connections to the polyphase meters are the same as those employed in the two wattmeter method of measuring three-phase power, as shown in Fig. 7. Most polyphase instruments, however, utilize two or more single-phase elements mounted in a single shaft, which drives the dial. These elements must be shielded from each other to avoid interaction between the fluxes produced by individual elements. For instance, three-phase energy can be measured by having three watt–hour meters with current coils in each line and potential coils connected across the given line and any common junction. Since the common junction is completely arbitrary, it may be placed in any of the three lines. When this is done, the watt–hour meter connected in that line will indicate zero energy, because its potential coil has no voltage across it. Therefore, the third watt–hour meter can be dispensed with, and the three-phase energy can be measured with only two watt–hour meters. In general, m-phase energy can be measured by $m - 1$ watthour meters.

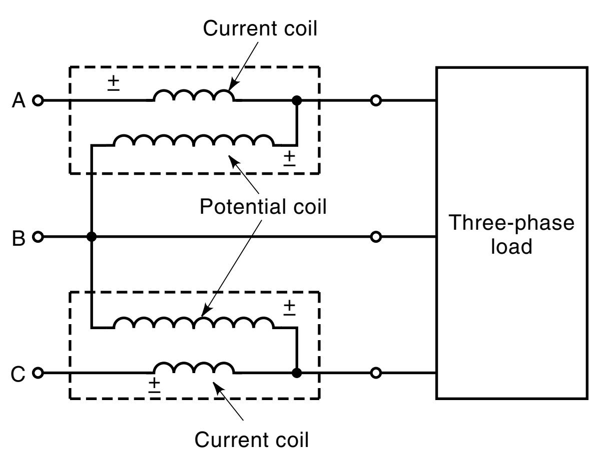

Figure 7. Connection diagram for polyphase watt–hour meter method of energy measurement.

Polyphase Watt–Hour Meter Connections. It is crucial to ensure appropriate connection of the various components of a polyphase watt–hour meter for registering accurate results. In a three-phase circuit, when the power factor is 1 corresponding to resistive loads, both watt–hour meters as shown in Fig. 7 will indicate the same reading; that is, the disk rotation will be in the forward direction at the same speed. If the power factor is above 0.5, the disk rotation will always be forward whenever the current or the potential coil of either of the two watt–hour meters is disconnected. On the other hand, if the power factor is less than 0.5, the disk rotation of the two watt–hour meters will be in the opposite directions. It should be mentioned that if the current coils of the two watt–hour meters of Fig. 7 are interchanged and the power factor is 0.5, the meter reading will be 100% wrong although it will run at normal speed.

Induction Watt–Hour Meter Adjustments. All adjustments of induction watt–hour meter are usually made either at full load or at light load. To adjust the speed at full load, the drag magnet is usually shifted relative to the disk axis. Alternatively, speed adjustments can be made by using a movable soft iron bar for shunting the flux. To compensate for variations in ambient temperature, a small piece of temperature-sensitive iron–nickel alloy is generally used as a shunt in the air gap of the drag magnets.

MICROPROCESSOR-BASED ENERGY METERS

Microprocessor-based systems are increasingly being used in energy measurement. Figure 8 shows the simplified block diagram of a microprocessor-based energy measurement system

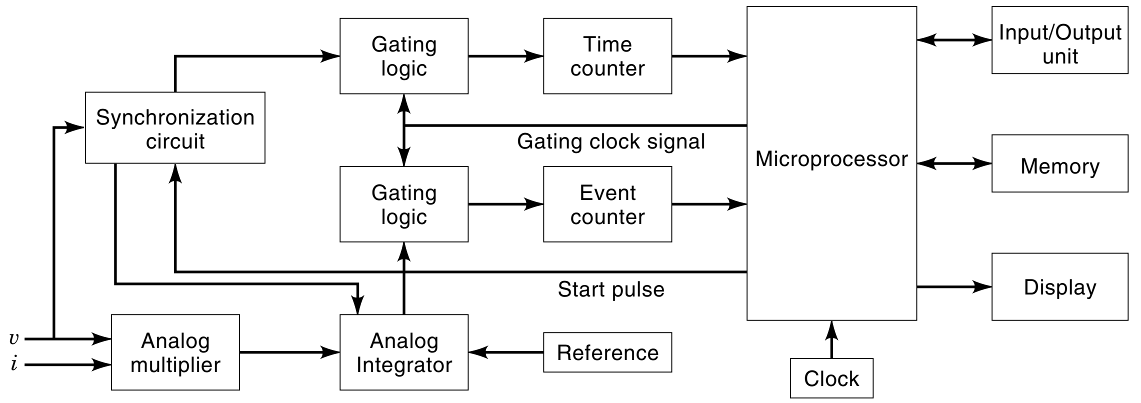

Figure 8. Simplified block diagram of a microprocessor-based energy meter.

employing synchronous counting (3). The system consists of an analog unit and a digital unit. The input signals v and i are multiplied in an analog multiplier. An analog integrator, such as a dual slope converter, performs integration on the multiplier output signal over a time interval T_i. The microprocessor sends a start pulse of suitable duration to activate the synchronization circuit. The synchronization circuit, after synchronization with the input signal v, generates a signal of duration T_i, which controls the time counter gating logic. Notice that T_i is the period of integration for the multiplier output signal and is always equal to an integer multiple of the input signal period. Subsequently, the analog integrator integrates a reference signal over a period T_j, which is measured by the time counter. The microprocessor keeps track of the entire duration (T) of measurement using an internal counter. The outputs of the event and time counters are fed into the microprocessor system, which internally calculates the total energy and outputs the calculated or measured energy on the display. With microprocessor-based energy meters, an accuracy of the order of 0.1% can be achieved.

REACTIVE VOLT-AMPERE-HOUR METERS

Reactive energy is defined as the quantity measured by a perfect watt–hour meter that carries the current of a single-phase circuit and a voltage equal in magnitude to the voltage across the single phase circuit but in quadrature therewith (4). Reactive energy is often measured at single-phase and three-phase services. Reactive energy measurement is generally more complex than active energy measurement because additional processing of input signals is necessary. The most common reactive energy meters are watt–hour meters with the currents through the voltage coils displaced by 90°. To provide this 90° phase shift various methods such as potential cross phasing, RC and RLC circuits, varformers, digital phase shifting in sampling meters, and electronic integrators in time-division multiplier meters are used (5). If the voltage across the single-phase circuit is given by

$$v = |V| \sin\theta_v \tag{15}$$

then the voltage in quadrature is given by

$$v = |V| \sin(\theta_v - 90^\circ) \tag{16}$$

From the point of view of measuring system design, it is irrelevant whether the phase shift is performed on the voltage or on the current signal. Only the phase displacement between the input signals is of importance. Figure 9 shows the simplified block diagram of a reactive power and energy measurement system. At first, the voltage signal is given a 90° phase shift in the phase shifter; it is then multiplied with the current signal in the analog multiplier. The output signal from the multiplier unit, that is, the reactive power signal, is introduced into an analog-to-digital converter (ADC). The integrating unit inherent in any ADC provides the power integration step to generate the reactive energy, which after some intermediate processing is shown on the display unit. It should be mentioned that, for nonsinusoidal signals, the reactive energy of the fundamental frequency is usually the dominant reactive energy component. Therefore, the measurement of that component is most important. For better accuracy, additional higher harmonic terms may be incorporated.

METER RATINGS

The rise in temperature resulting from the losses in a meter must be accounted for when rating a meter because meter

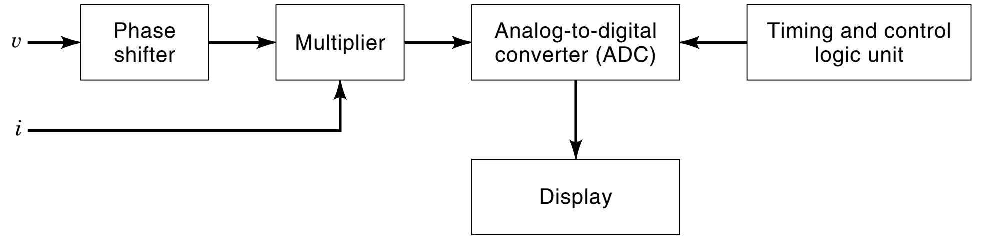

Figure 9. Simplified block diagram of an electronic reactive energy measurement system.

life span should not be unduly shortened by overheating and consequent deterioration of insulating materials surrounding the current carrying conductors. In general, a general purpose meter should have a lower permissible temperature than a special purpose meter to accommodate a greater factor of safety. In the past, watt–hour meters were rated only at the full load which is currently referred to as the test ampere (TA) rating or test current rating. The TA rating is indicated on the nameplate by the manufacturer and is mainly used for test constant calculation as well as for determining and adjusting the percent registration of a meter at light and heavy loads. The percent registration of a watt–hour meter is defined as the ratio of the actual registration to the value of the quantity measured during a given time interval. Currently watt–hour meters are rated into a number of classes based on their maximum capacities. A class such as 10, 20, 100, or 200 usually indicates the peak of the load range in amperes.

RECENT TRENDS

Power and energy measurement using electronic systems, microprocessors, and digital techniques is becoming increasingly popular. Such systems can provide greater versatility and accuracy, and afford the potential to transmit data without the need for a meter reader. Since electronic systems are often smaller and lighter than electromechanical systems, these systems may be more portable as well as less expensive.

Switching devices, such as silicon-controlled rectifiers (SCRs), that draw current from the line during only a portion of the cycle are becoming commonplace. This trend has added to the problems of power companies, since the switching process generates harmonics of the line frequency, which have repercussion upon both customer and the supplier of electrical power.

As mentioned earlier, electronic equipment can be used in versatile ways to aid in measuring energy. The portable tester is one of the latest electronic gadgets to help us with energy measurement. Until recently a meter could only be tested by pulling it and taking it back to the shop. However, portable testers effectively alleviated that problem. They are especially helpful when customers live in remote areas.

ACCURACY

Electric utilities all over the world use single-phase watt–hour meters to measure residential energy consumption. Since the watt–hour meter serves as the cash register for the utility, both the utility and the regulatory body have a high interest in its accuracy. In order to ensure that the customers are not charged for more energy than they consume and the utility collects the revenue to which it is entitled, watt–hour meters are sampled on an annual basis, ensuring accurate registration of energy. Typically the sampled meters are sent to a central testing facility and tests are performed to indicate how accurately the meters are performing in service. The results of these sampled tests are reported to the regulatory body to satisfy its rules and regulations. The utility also uses statistical tools for determining the performance of the meter population.

Single-phase watt–hour meters typically used in residential service are three-wire, 240 V, and class 200 (6). These meters are generally tested at two test load points: full load (FL), which is defined as 30 A, and light load (LL), which is defined as 3 A. In order to get an indication of how a meter performs over a load range of 0 to 200 A, the test results at full load and light load are weighted to yield an overall accuracy. The overall accuracy (OA) equation is written as

$$\mathrm{OA} = \frac{4 \times \mathrm{FL} + \mathrm{LL}}{5} \tag{17}$$

For example, if the full-load accuracy is 100.2% and the light-load accuracy is 95%, then the overall accuracy is 99.16%. This method is one of the two methods recognized by the utilities. The second is the true average method. In this case the overall accuracy equation is defined as

$$\mathrm{OA} = \frac{\mathrm{FL} + \mathrm{LL}}{2} \tag{18}$$

The second method is not in widespread use.

Energy meters are also classified as *precision grade* or *commercial grade,* depending on the degree of accuracy with which they make measurements. Commercial grade meters are those generally met with in ordinary factory and home service installations. Precision grade meters are designed to have negligible error and are retained exclusively for test-room measurements thus making them expensive.

Because of its low cost, the inductive watt–hour meter is still the most widely used energy meter. It is practically the only meter used in the residential sector. The accuracy of most inductive watt–hour meters is typically 1% for sinusoidal operation at a fixed frequency. Recently, energy meters based either on digital sampling or on time-division multiplier became available, which are very accurate (∼0.1%) compared to the inductive watt–hour meters.

CALIBRATION

Phantom loading of watt–hour meters is a common method for their calibration. This mainly consists in supplying sources of calibration voltage that are independent of each other at one point and are adjustable. This practice has several advantages over the use of resistive and reactive loads, such as (1) better adjustment of voltage, current, and power factor in the laboratory, (2) reduced need for large current supplies, and (3) elimination of errors that might result from failure to take into account losses or loading effects in the test and reference instruments. Figure 10 shows two circuits commonly used in the calibration of watt–hour meters. In Fig. 10(a), the current circuits are connected in series and supplied with a stepdown transformer for the test and reference instruments. This isolates the current circuit from the voltage circuit. A smaller series adjusting resistor may also be used for adjusting the load current. This method is used when it is desired to simulate a unity-power-factor load. The voltage of the current supply transformer must be high enough so that it swamps the reactance of the current circuits of the meters. The circuit in Fig. 10(b) is used when low-power-factor loads of the order of 50 are desired. By using a

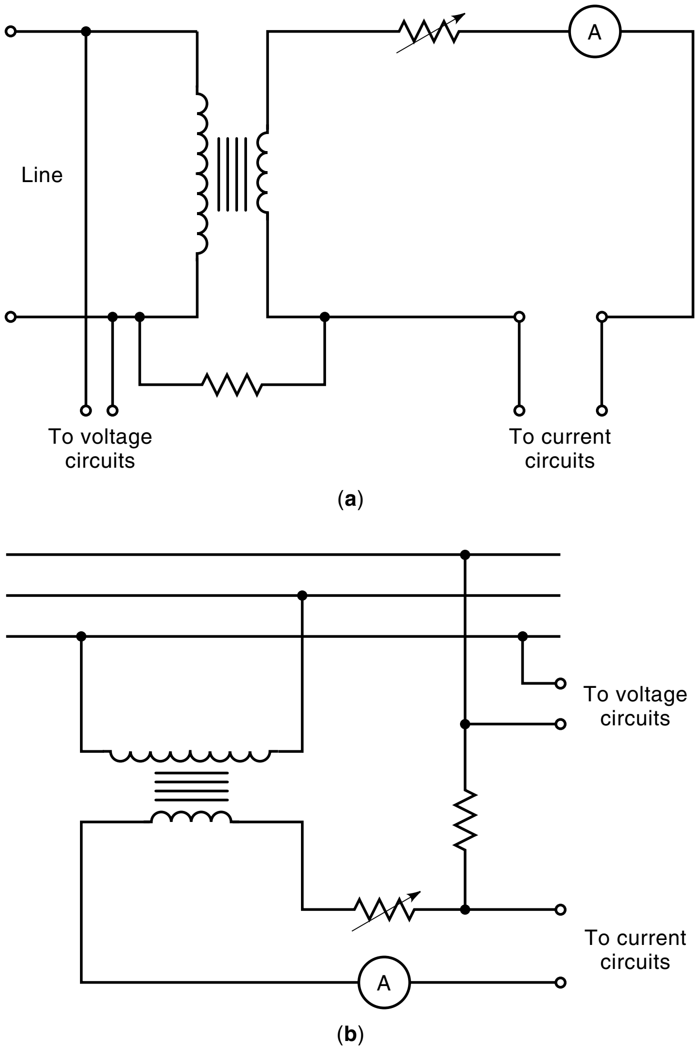

Figure 10. (a) A basic calibration circuit for a watt–hour meter, and (b) a more sophisticated version of the calibration circuit.

three-phase supply and taking the current supply from one phase and the voltage supply from another, it is possible to simulate low-power-factor loads if the phase angle is known. The phase for the voltage supply can be selected to lead or lag the current of the secondary of the supply transformer by 60°.

PORTABLE METER READING AND STANDARDS

Presently utilities all over the world are debating whether to incorporate *automated meter reading* (AMR) in their systems. AMR offers many other advantages than just remote meter reading. An AMR system can signal outages, perform remote connect and disconnect, deter meter tempering, prevent lockouts, and facilitate time-of-use metering. In addition, utilities can offer value-added services such as forced-entry alarms and low- or high-temperature alerts. Any of these can generate revenue. Over 30 vendors are in the AMR market, offering systems of every size and kind (7). The systems vary according to the communication media used, whether they are one-way or two-way, whether they read meters at high or low speed, and whether they are fixed or mobile. Utilities have been slow to adopt automated meter reading systems because the investment is high and the payback is slow. Other reasons include reluctance to change, discomfort with new technology, and long-term satisfaction with walkaround readers. Furthermore, AMR system requires a coordinated, horizontal effort across the utility, involving metering, billing, customer service, and information systems.

The most widely used technique for watt–hour meter testing is called portable standard or rotating standard. Portable standards are transportable watt–hour meters with multiple current and voltage range and allows both whole and fractional reading. Initially, energy is measured by using the watt-hour under test. Then the portable standard meter is used to measure the same energy. The accuracy is determined by comparing the readings of the two meters.

REFERENCE STANDARDS

For ac watt–hour meter testing, a time reference standard such as a clock or a stop watch and a wattmeter may be used. Alternatively, a watt–hour meter is used as the reference standard which is started and stopped automatically by a signal (e.g., light) generated from the meter to be tested. For dc watt–hour meter testing, the reference standard may be ammeters and voltmeters or potentiometers.

Standards and technical practices are an essential tool in any field, and energy measurement is no exception. In the USA, approximately half of all standards are generated through a voluntary consensus process (8). Most engineering standards are developed by technical societies and trade associations. The private sector rather than the government generates the standards. The American National Standards Institute (ANSI) coordinates the voluntary development of standards in the USA. ANSI is a nonprofit organization composed of corporate members, trade associations, and technical societies. It is self-designated in its role in standard coordination and does not develop any standards. ANSI reviews the documents produced by others and certifies them as American National Standards. The Institute of Electrical and Electronic Engineers (IEEE) is the primary producer of electrical documents for ANSI. Other major nongovernment standard organizations producing electrical standards are the American Petroleum Institute (API), Associated Edison Illuminating Companies (AEIC), the National Electrical Manufacturers Association (NEMA), and the National Fire Protection Association (NFPA).

CONCLUSION

In this article we started off by defining some basic terms that would allow us to understand different aspects of energy measurement. We then described different types of energy-measuring instruments in detail, and briefly discussed some of the latest trends in energy measurement. All these topics were chosen by keeping in mind the diverse readership of this encyclopedia. With our present dependence on energy it is necessary that a wide section of the population become aware of different aspects of energy measurement.

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ENERGY MEASUREMENT, AC AND DC. See ENERGY MEASUREMENT.

ENERGY, NUCLEAR. See NUCLEAR ENGINEERING.

ENERGY SPECTRAL DENSITY. See SPECTRAL ANALYSIS.

ENERGY STORAGE. See CAPACITOR STORAGE; POWER QUALITY.

ENERGY STORAGE BY BATTERIES. See BATTERY STORAGE PLANTS.

ENGINEERING. See VALUE ENGINEERING.

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ENGINEERING, CONCURRENT. See CONCURRENT ENGINEERING.

ENGINEERING EDUCATION, ELECTRICAL. See ELECTRICAL ENGINEERING EDUCATION.

ENGINEERING ETHICS. See ETHICS AND PROFESSIONAL RESPONSIBILITY.

ENGINEERING, INFORMATION. See INFORMATION TECHNOLOGY.

ENGINEERING, MEDICAL. See BIOMEDICAL ENGINEERING.