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A NEW METHOD FOR ENERGY ACCOUNTING IN INTERCONNECTED OPERATIONS

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The measurement of electrical energy supplied to customers or purchased from and delivered to interconnected power systems is of paramount importance in power system operation. Accurate measurement of energy delivered to customers or received from and delivered to other systems is necessary to ensure that billing is correct.

Energy transferred between systems also must be properly measured and accounted for to ensure that agreed-upon schedules are being met, and that each system meets its obligation to match generation with load on a moment-to-moment basis

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INTRODUCTION

Prior to the development of integrating watt-hour meters, flat rates, determined by the number of lamps or other connected loads, were used for billing purposes. This was a very unsatisfactory method of billing, since there was a poor match between the cost of service and the price. One customer might have equipment in service continuously while another customer with identical equipment might operate it for only a few hours during the day. Both customers would pay a similar price for widely dissimilar energy usage.

An analogous situation still exists with some small water systems, where customers are billed on the size of the pipe serving their property rather than by the actual water use. Such flat-rate systems are becoming very rare, however, as metering equipment becomes more universally used and provides a much more equitable means of billing for service.

Power in an electrical circuit with unity power factor is the product of the potential (volts) times the current (amperes) and is expressed in watts. For high voltages (kilovolts) and currents (hundreds or thousands of amperes), this product may be expressed as kilowatts or megawatts, and for very low voltages (millivolts or microvolts) and currents (milliamperes or microamperes) may be expressed as milliwatts microwatts.

In dc circuits power is always the product of current times voltage; however as discussed in chap. 1, in ac applications, for circuit containing inductive will lag the voltage, and for circuits containing capacitive reactance , the currents will lead the voltage.

Most circuits contain both inductive and capacitive reactances, and the currents may lag or lead the voltage depending upon which reactance is predominant.

The cosine of the angle θ between the current and voltage is referred to as the power factor. The product of the current times the cosine of the angle gives the component of current in phase with the voltage, that is,

$E.\ I.\ \cos\theta$ = power (W)

The component of current, lagging or leading the voltage by 90^0, which is the current times the sine of the angle between the current and voltage is referred to as the reactive component.

$E.\ I.\ \sin\theta$ = volt-amperes reactive (var)

Although frequently referred to as reactive or wattles power, there is no power in the reactive var.

Var flows in a circuit always increase losses as the current in circuit with the same load (power) and with a reactive component is greater than that in the same circuit with a unity power factor load. The loss in any circuit is due to the resistance in the circuit and is the square of the current times the resistance or I^2R watts, where I is the current in amperes and R is the resistance in ohms. This loss can become significant in circuits with appreciable resistance and significant reactance, resulting in load currents greater than would be required to supply the connected loads in high-power-factor circuits.

In many cases considerable effort and money are expended to reduce the losses due to reactive flows by improving the power factor of a circuit the installation of capacitors or inductors as required to reduce the reactive components of the load currents.

MEASUREMENT TO ENERGY

The revolving-disk watt-hour meter was developed in the early days of the power industry and is still used to measure energy deliveries or transfer. These devices use motor mechanisms in which rotor elements revolve at speeds proportional to the flow of power in the circuits. They are equipped with registering devices which are gear-driven from the motor mechanisms so that the amount of energy used is integrated.

These types of meters have not changed basically over a long period of time, although there have been many improvements in their design and construction. Electronic meter have been developed in more recent years, although the revolving-disk meters are still in wide use.

For domestic, meters are usually single phase, but in power plants and industrial application polyphase meters are frequently used, where one or more driving disks are mounted on a common shaft so that one meter will register total energy in a polyphase circuit.

In order to measure power, meters must have potential (voltage) elements and current elements. The potential elements are usually winding rated at 115 or 230 V. The current winding ratings are determined by the connected load for usual domestic applications.

INSTRUMENT TRANSFORMERS

In order to measure energy at the high voltages and currents used in power systems, or with large electric machines, it is necessary to reduce voltages and currents to values within the ranges of the meters, relay, or other equipment that may be used in a particular application. This is accomplished by the use of instrument transformers.

Current transformers are used with primary winding of very few turns (sometimes only one) that must have conductor sizes adequate to carry the current in the line. The secondary winding consist of many turns of small conductor with a turns-winding ratio expressed in primary amperes to secondary amperes, such as 100:5, 600:5, or 1000:5. The actual turns ratios of the above transformers would be 20:1; 120:1, and 200:1.

Because the primary winding of a current transformer is in series in the line and is at line potential, for high – voltage application current transformers are supported by porcelain or other insulation adequate to withstand the voltage of the line, and there must be sufficient insulation between the primary and secondary windings to withstand the voltage between the windings.

All transformers are actually voltage-operated devices. In current transformers, with rated line current flowing in the primary winding, there will be voltage drop (of small magnitude, millivolts) across the winding, adequate to cause rated secondary current to flow. It may be in order to point out that current transformer secondary windings should always have a closed circuit across their secondary terminals. Because of the high ratio of secondary to primary turns, extremely high voltages can result in current transformer secondary windings if they are open-circuited. Normally a short-circuiting switch is provided on switchboards so that if the current transformer secondary has to be opened for any reason, such as testing or additions of equipment in the secondary circuit, the shorting switch is closed to prevent the possibility of the occurrence of high voltage, which could be lethal for those working on the circuit, or cause damage to the switchboard equipment.

Potential transformers for power system applications will typically have winding ratios such as 300:1 for 60-kV applications, 600:1 for 115-kV, 1200:1 for 230-kV, etc. These transformers are usually connected line to ground, so that the line-to-line voltage is the indicated meter voltage times the transformer ratio times 1.73 ($\sqrt{3}$). For example on a 115-kV system with a 600:1 potential transformer and 120 V indicated on a voltmeter, the actual line voltage would be 120.600.1.73 or 124,560 V (124.56 kV).

Capacitor potential devices may also be used for voltage measurement. In these cases, a series of capacitors are used as a capacitance voltage divider. The capacitor unit nearest ground potential has a voltage across it that is used to supply the primary of a small potential transformer. The voltage is much less then the line voltage, so that the potential transformer dose not requires the high-voltage insulation that is necessary for a transformer connected to the line. The secondary of the transformer is normally 120 V, the same as the usual line potential transformer.

Since a lower-voltage transformer can be use without the requirement for high-voltage insulation, these devices are less expensive than conventional potential transformers .Furthermore, the same capacitor can be used to couple power line carrier voice or relaying equipment to the high-voltage line. However the accuracies of capacitor potential devices are not as good as the normal line-to-ground potential transformer.

There are two classes of capacitor potential devices, class A and class C. The class A devices has accuracies approaching those of normal line-to-ground potential transformers and is sometimes used for metering purposes. The class C device is less accurate and is often used for metering other than for revenue purposes, that is, for indicating meters and relaying. Usually capacitor potential devices, although not as accurate wound transformers, serve very well for these applications.

An item to be considered in all applications of instrument transformers is the burden (load) that will be applications to them. These transformers are rated in volt-amperes, and the rating should not be exceeded, since the accuracy of the metering involved will be reduced if excess burden is placed on the instrument transformers.

METERING ARRANGEMENTS

There are various connection arrangements for metering three-phase power. Usually either the “three-wattmeter” or “two-wattmeter” method is used. These methods are well described in electrical text-books and will not be discussed here. This discussion is primarily concerned with measuring energy at voltages and currents used in power system which require the use of instrument transformers (current and potential), as described above.

It should be obvious that when current and potential transformers are used, the metered indication will have to be multiplied by the ratios of both sets of transformers to determine the energy actually delivered.

As an example, assume the metering installation shown in figure 1. With the instrument transformers shown, voltage and current readings would be multiplied by

$$\frac{(400/5).600.3}{1000} = \frac{80.600.3}{1000} = 144$$

to determine the actual power in kilowatts in the circuit. For example, if the load current reading was 4 A and the voltage reading was 120 V, the power in the circuit, assuming unity power factor, would be 6912 kW.

Ammeters used in connection with current transformers are usually calibrated to read actual line current, taking into consideration the current transformer secondary voltage. In order to obtain actual line voltage, it is necessary to multiply the indicated reading by the potential transformer ratio. However, the meters may be calibrated to read actual line voltage.

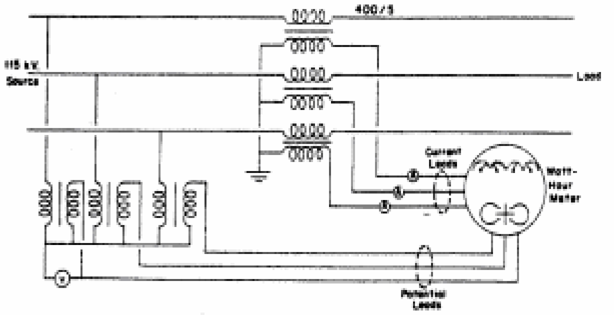

Figure 1 Typical three-phase metering installation using current and potential transformers.

Indicating watt and var meters are frequently installed on transmission-line terminals so that operators can see real and reactive power flows and the effect on reactive flow of generator field or other voltage-control-device changes.

In measuring energy, time becomes a factor. The product of current, voltage, and power factor gives power in a circuit only at the instant at which the readings were taken. However , if current and voltage remain constant for period time , such a 1 h , the energy used or transported will be the indicated watts times 1 h , or watt-hours. Mathematically expressed, energy is watts. Time (hours) = watt-hours.

Since a watt-hour is a relatively small unit, it is usual to express energy in kilowatt-hours or megawatt hours. One kilowatt-hour = 1000 watt-hours and megawatt hour = 1,000,000 watt-hours.

Measurement of energy is accomplished by the use of integrating watt-hour meters. Essentially, such meters consist of an electric motor whose speed of rotation is proportional to the amount of power flowing in the circuit. The shaft of the motor rotor (disk) is connected through a gear train to indicating dials. The watt-hour meter adds all the instantaneous power in a time period to indicate the energy (power. time) used by load or transported in a circuit in the time period.

As previously mentioned, watt-hour meters usually have current and potential coils of relatively low rating, and in power system applications are used with current and potential transformers. In addition to the multiplying factor resulting from the instrument transformers, the gear train from the meter disk to the indicating dials also introduces a constant multiplying factor. By proper selection of the gear train, the total multiplying factor can be made to equal some convenient constant, such as 1000 or 10000.

The energy measured by an integrating watt-hour meter is always obtained by taking the difference between a present reading and a previous reading and multiplying by the meter constant.

Energy supplied to customer loads is usually determined directly by integrating meter reading. This is also true in determining the energy produced by a generating unit where daily, weekly, or monthly readings may be taken, depending on the desired time period.

MEASUREMENT OF REACTIVE FLOWS (VAR)

Reactive flows (var) are measured with the same type of instruments and in the same way that active power is measured, except that the potentials used in var or var-hour meters are 90 out of phase with the currents.

INTERCHANGE NEGOTIATIONS

Planned interchanges between systems result form negotiations between operating centers that are parties to an interconnection agreement. They are, of course guided by contractual arrangements that have previously been established by the managements of the systems associated in the interconnection group.

There are various of negotiations that can be involved, such as

- Energy, firm-long term and short term
- Economy
- Emergency
- Capacity-firm, economy, spinning reserve

In most cases, after a system has agreed to purchase energy or capacity, it will be obligated to pay for the agreed-upon energy or capacity whether or not it actually takes delivery.

FIRM ENERGY

In some cases contractual provisions may require that acquire that capacity and energy contracted for must be paid for whether or not it is actually delivered. A system may be deficient in generating capacity and associated energy for various and such deficiencies may be expected to persist over a considerable period of time or be only temporary. In some cases the cost of installation of new facilities may be greater than the cost of purchasing energy for an extended period. In areas with considerable hydro capacity for an example, a dry year can limit the availability of power from that source for a period of several months.

In such cases, if power is available from another system, it can be purchased, and most interchange contracts have provisions for such transactions. These cases would normally be considered to be long-term firm. The selling company is generally obligated to make its best efforts supply the requested energy, short of jeopardizing its own load or prior firm commitments.

On the other hand where a deficiency exists or expected to exist for only a few hours or perhaps days, energy purchased would be considered to be short-term firm.

Interchange agreements will normally carefully define these categories, and the terms and conditions will also be spelled out in the agreements.

ECONOMY ENERGY TRANSACTIONS

This subject was discussed in Chap. 4, along with an example of an economy interchange transaction, but it may be well to provide a little more background on the subject .Economy energy transactions occur when there are alternatives to be considered, for example, in the production, sale, or purchase of power. In such cases, the decision to purchase or not purchase power is based on the relative economics in each case and will involve incremental costs and decremental valuse, also considering the transmission losses (penalty factors) involved in the delivery of the power to the tie point between the systems.

EMERGENCY POWER

Emergency power transactions are also normally provided for in interconnection agreements. Such provisions cover situations where loss of transmission lines or generattion facilities result in a deficinecy in generation in one that requires the purchase of energy from another system.

Wheeling of power occurs when there are one or more systems between the purchasing and selling systems. When power is wheeled through other systems, the additional power flow increases the losses in the transmission facilities of the intermidiate systems. Interchange agreements cover these situations and provide the terms for reimbursement of the intermidiate systems for such increased losses and the use of their transmission facilities.

SPINNING RESERVE

Interchange agreements normally indclude requirement for reserve capacity to be maintained by the systems involved in a power pool and by other participants involved in an iterconnection.

Spinning reserv is the amount of capacity that is maintained in a system, over and above its expected pack load, to provid for the loss of generating or transmission capacity. If there is insufficient spinning reserve, the svstem sustaining the loss may not be able to match generation with load and will impose a burden on other systems of the inteconnection.

Spinning reserve policies are established by each system and may specify the loss of the largest generator or most heavily loaded line, or may be expressed as a percentage of the peak demand for the day. Interchange agreements normally include spinning reserve requirements and may include penalties for failure to maintain the contractually required reserve.

Also, a system may purchase interruptible energy from another system, which can be interrupted without notice. It should carry sufficient spinning reservecapacity with energy capablility, and may be required by cotract, to produce the energy lost by such an interruption.

Conversely, if a system is selling interruptible energy to another system, the capacity required to produce this enrgy may be considered as a part of its spinning reserve since the sale can be interrupted at any time.

The maintenance of spinnig reserve is an expense,but prudent management requires that such reserve be maintained for emergencies. In some cases it may be difficult to maintain the desired, or required spinning reserve.

Interconnection agreements often provide for the purchase of reserve from other systems that may have more than adequate capacitiy for their own needs. The amount of reseve capacity available for purchase may vary from day to day or even hour by hour.

In some cases purchase of reserve can result in cost savings, as it may aviod the cost of starting a generating unit for a short period of time, which may involve considerable cost.

OPERATING RESERVE

Total operating reserve of a system may be much greater than that spinning at a particular time and includes capacity, both hydro and thermal, that is available and that can be started as needed. It is such capacity that can be made available for sale to other systems.

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