Power Transducer User's Guide

Volume 1

MOORE INDUSTRIES®

Power Transducer User's Guide

Volume 1

Applying Power Transducers

Volume 1

I. Why Monitor Power?

With ac power consumption and measurement drawing ever-more attention throughout the process industries, an understanding of basic ac parameters becomes increasingly important.

This simple reference guide uses illustrations and simple definitions to explain the basics of ac power and its uses in the process industries. This comparison shows the relationship between the terms used in measuring electrical current and standard process flow concepts:

Electrical Term	Flow Term
Current Voltage Resistance	Flow Pressure Pressure Drop

Keeping this simple analogy in mind should help you understand and apply the basic principles needed to use power transducers.

For help in controlling your ac power usage, or ordering power transducers, please call your local representative. In addition, our helpful Sales Engineers are available during business hours. Please consult the back of this booklet for the phone number of the office nearest you.

II. Beginning Definitions

Prior to reading further in this booklet, please familiarize yourself with these basic terms of electricity and ac power measurement.

Ampere—The basic unit used to measure current, often abbreviated as “amp” or “A.” It equals a unit of electrical current or the rate of flow of electrons. One volt across one ohm of resistance results in current flow of one ampere.

Current —The movement or flow of electrons through a conductor, represented by the letter symbol “I.”

Voltage—The force causing current to flow through a conductor, represented by the letter symbol “E.” The unit of measure is the volt, or “V.” One volt equals the force required to produce a current flow of one ampere through a resistance of one ohm.

Element—The portion of a transducer which senses one input each of voltage and current.

Impedance—As current flows through a conductor it encounters force which blocks its path. The force consists of passive components (resistance) and reactive components (inductive and capacitive reactance.) Impedance is measured in ohms and the symbol is “Z.”

Resistance—Component of impedance due to passive elements of the load. Resistance is represented by the letter symbol “R.” One unit of resistance is known as an ohm.

Reactance—Component of impedance due to active elements of the load. Symbol is “X.”

Ohm—A single ohm equals the amount of impedance that will limit the current in a conductor to one ampere when one volt is applied to the conductor, represented by the Greek letter “Ω.”

Frequency—The number of times that the variations of an alternating current represented by the sine waveform are repeated during one second of time, expressed in hertz or “Hz.” One hertz equals one cycle per second.

Custom Transducer Calibrations

If we use the same transducers and transformers as in example 1, and say that the customer has a meter that is already scaled for 0-60,000 watts, we have to work in reverse to determine the appropriate calibration point for the transducer. We would take the 60,000 watts and divide this by the transformer ratios:

$$\frac{60{,}000}{\frac{480}{120} \times \frac{100}{5} \times 2\ \text{ELEMENTS}} = 375\ \text{WATTS/ELEMENT}$$

In order to get 60,000 watts full scale with the customer’s transformers, we would have to calibrate the transducer to 375 watts per element.

III. Basic Concepts of Ac Power

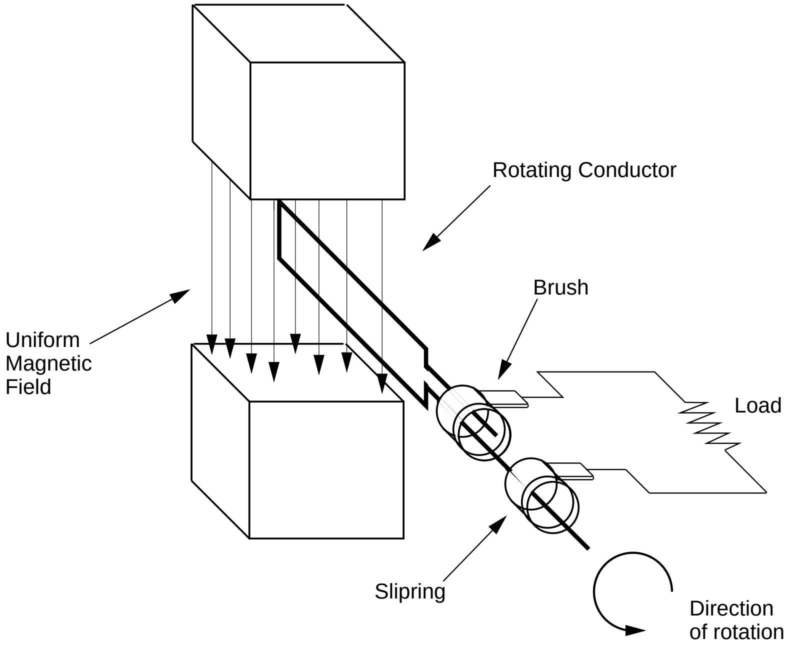
This material should give non-electrical engineers a feel for some of the basic characteristics of electrical systems. Ideally, this information will help you implement and work with an energy monitoring and management system.

Power—Direct Current Circuit

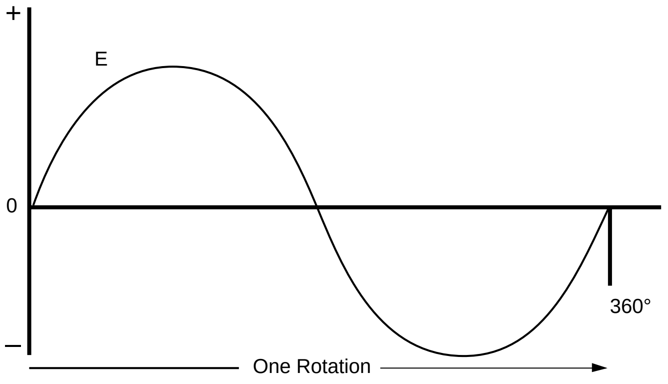
In a direct current circuit voltage and current are constant. There are only resistive loads. The relationship between voltage, current and resistance is E = IR. Power is defined $P = EI = I^2R$. A watt is one volt times one amp. 1W = (1V) (1A).

Power—Alternating Current Circuit

Alternating current is created by rotating a coil of conductive wire through a magnetic field (Drawing 1). Drawing 2 represents the results of the rotating action through the magnetic field. In an ac circuit, voltage and current vary in amplitude in a sinusoidal fashion.



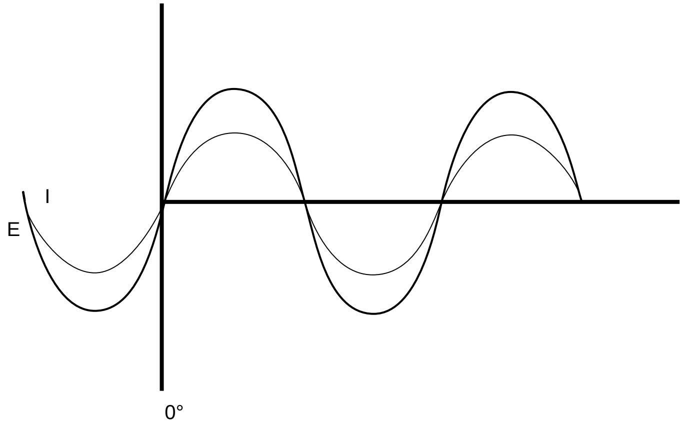
Drawing 1. *Typical ac motor*



Drawing 2. *One rotation of an ac motor*

Resistive Load

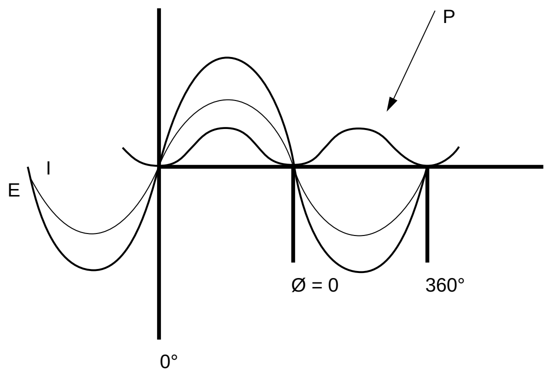
When this coil is wired to a purely resistive load, the voltage and the resulting current occur simultaneously. In other words, they are rotating "in phase" (Drawing 3).



Drawing 3. *Resistive Load*

The power is defined as P = EI cosØ, where Ø is the phase angle between the voltage and current. Here (Drawing 4) the angle is zero. CosØ = 1, so P = EI and alternates between some positive value and zero.

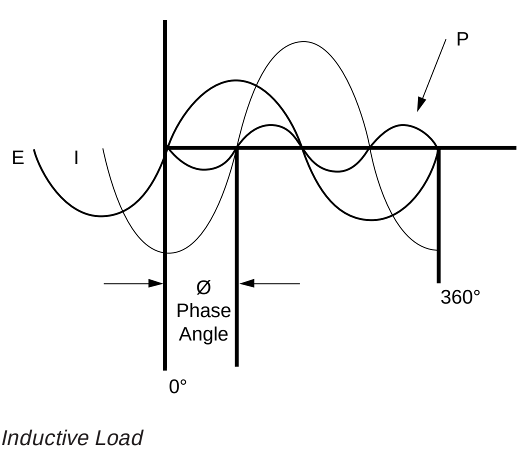
Drawing 4 shows instantaneous values of the voltage, current, and power. The quantities used in the equations and in the applications are the RMS (root mean squared) values.



Drawing 4. *Current, voltage and power values of a resistive load*

Inductive Load

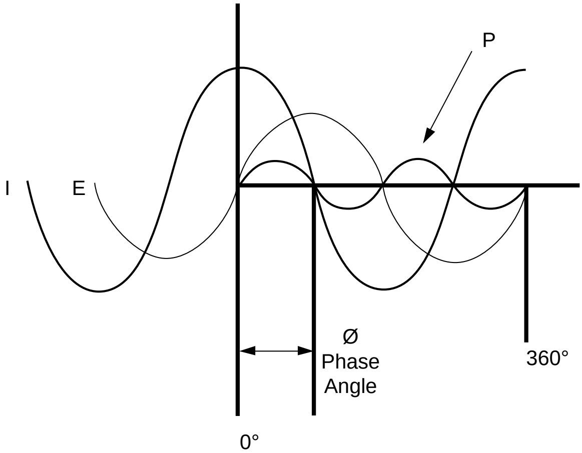
When the applied load is a pure inductance, the current will lag the voltage by 90°. Phase angleØ = 90°. The resulting power: P = EI cos(–90°) = 0. The product of E and I varies between equal amounts of positive and negative values resulting in an RMS value of zero power (Drawing 5).



Drawing 5. *Inductive Load*

Capacitive Load

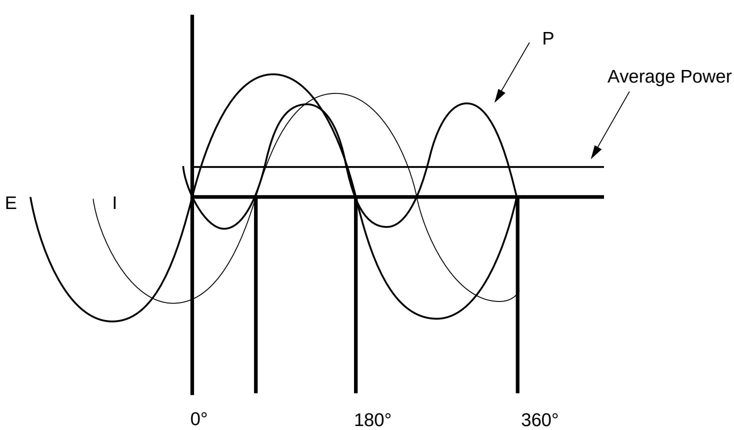
When the applied load is a pure capacitance, the current will lead the voltage by 90°. Phase angle = 90°. P = EI cos90 = 0. Again, RMS power is zero (Drawing 6).



Drawing 6. *Capacitive load*

Real Loads

In actual practice loads are never purely resistive, inductive, or capacitive. For an example, let's consider a circuit whose loads result in a small amount of inductive reactance. In this example (Drawing 7) the current lags the voltage by 60°.



Drawing 7. *Inductive and reactive loads*

Drawing 7 shows that there is more positive power than negative power, so the RMS value will be positive. P = EI cos60° = EI(0.5).

Real Power

So far when we have referred to power we have meant useful or real power, or power which does work. Real power = EI cosØ = I^2R = I^2ZcosØ. It is expressed in units of watts (watts = volts x amps x cosØ).

Apparent power

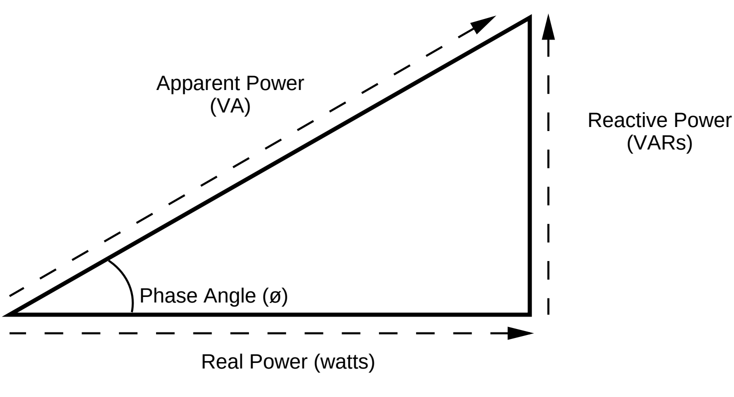
Apparent power is the product of the voltage and current without regard to the applied load or the phase angle. Its measured value is called “volt-amps” or VA. When a real world load is applied to the circuit a combination of real power and reactive power results.

Reactive Power

Reactive power is the result of the net reactance in the circuit. Rather than doing useful work, reactive power is stored in the magnetic and electric fields of the inductance and capacitance, then returned to the circuit. The unit for reactive power is VAR for volt-amps-reactive. Reactive power = EIsinØ = I^2ZsinØ.

Power Triangle

A convenient method to display the relationship between apparent, reactive, and real power and the phase angle is with the power triangle. The lengths of the sides of the triangle correspond to the relative values of the respective parameters.



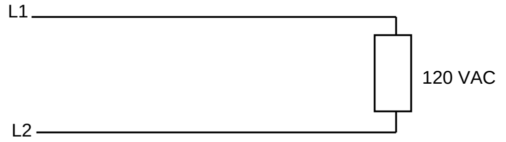
You can easily see that if the phase angle is zero, then the VARs are zero and apparent power = real power.

IV. Common Ac Power Systems

Ac power systems offer a number of configurations for using power. In most instances, you will encounter the four arrangements described in this section.

Single-Phase Two-Wire

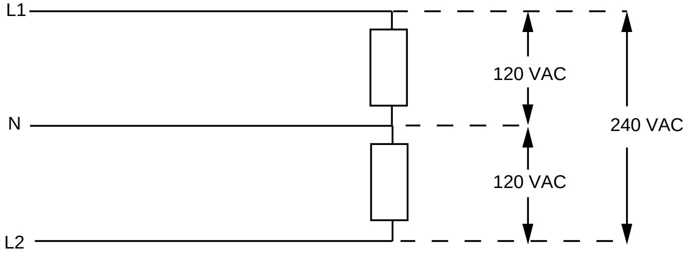
The most recognizable ac power system is the single-phase two-wire system. This configuration provides power within your home for operating domestic appliances like toasters and refrigerators.



The voltage on this type of circuit is measured and written as a line to line value. This illustration shows a 120 volt system. Measuring power on this system requires one voltage and one current measurement, or a one element transducer.

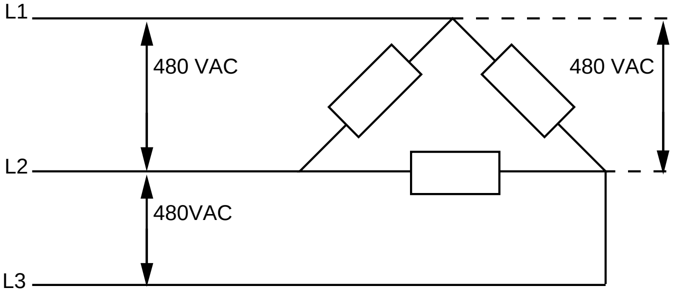
Single-Phase Three-Wire

This type of system provides electricity to homes in the United States and you will rarely encounter it in an industrial situation. The two wires and neutral leg comprise a single phase system. This system can be monitored with either a 1-1/2 or two element transducer so that the voltage and current on each phase may be measured.



Three-Phase Three-Wire

Most industrial motors and other equipment within the process industries operate with this type of system, commonly called a **delta** system.

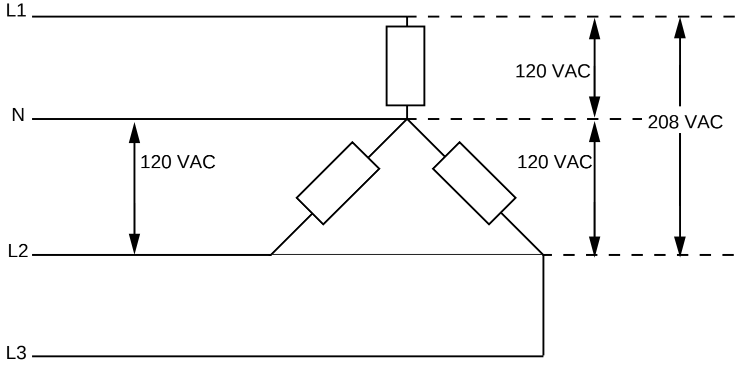


The voltage values are expressed as line to line values because no neutral is present. Monitoring this type of system requires a two-element transducer.

Three-Phase Four-Wire

You will find this type of system, consisting of three wires and a neutral, providing the entrance power to an industrial building. Common names for it include “wye” or “Y connected.”

Because the system has a neutral leg the voltages may be measured line to line or line to neutral. The proper description of this circuit uses both values (i.e. 208Y/120). Although commonly only the first value is used (208) for the purpose of power measurement we must use the line to neutral value (120ac)



In this example, 208 volts is the line to line value and the line to neutral value is 120 volts (line voltage divided by the square root of three). For the greatest accuracy, a three element transducer should be used for monitoring this type of system. If the system voltage is completely balanced (the voltages and loads on the three phases are equal), a 2-1/2 element transducer may be used.

Should you forget all these illustrations, use this helpful rule of thumb for determining how many elements a transducer should have for monitoring a particular system: subtract one from the total number of wires in the system.

(# of wires) - 1 = # of Elements

CONFIGURATION		Connection	RESTRICTIONS	
Code	Application		Voltage	Load
1E	1 Element	1 Phase	None	None
1.5E	1-1/2 Element	3 Phase, 3-wire	Balanced	Balanced
2E	2 Element	3 Phase, 3-wire	None	None
2.5E	2 1/2 Element	3 Phase, 4-wire	Balanced	None
3E	3 Element	3 Phase, 4-wire	None	None

V. Monitoring Common Ac Power Systems

Monitoring and recording the voltage and current used by any of the systems described above requires the use of volt and current transducers. The output signals from these transducers can be used to provide input to meters and activate alarms or other devices should current or voltage fall outside of a safety range.

Measuring Voltage

Ac voltage measurements occur across a source or a load. “Load” devices (such as heaters and motors) consume power. “Source” devices, such as transformers and generators, create ac voltage. Figure 1 shows a typical circuit for measuring voltage using a Moore Industries PAV Voltage Transducer. As the illustration shows, the output from the transducer should be carried on a twisted, shielded wire pair.

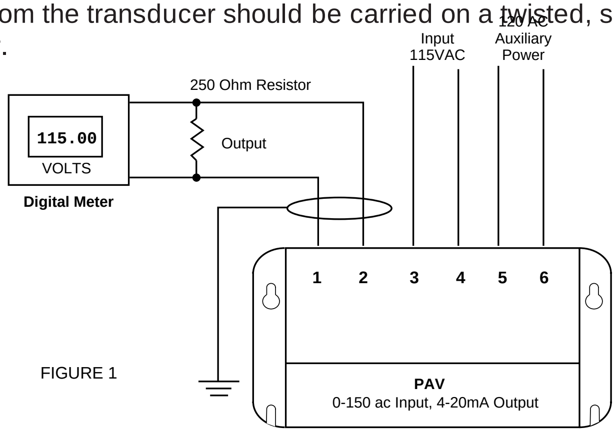


Figure 1.

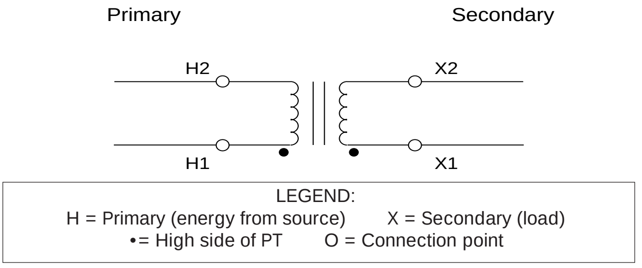
The above illustration shows measurement using the **direct connect** method. This requires using a measuring device which fits directly in to the circuit. An alternative method, especially popular in high voltage situations, requires using a **step down** device, known as a voltage or potential transformer (PT).

A step down device is a transformer that inductively senses the voltage, steps it down, and provides a proportional output. The stepped down voltage reduces the risk of injury to personnel.

The format used to express the ratio between the primary and secondary voltage places the primary voltage as the first number and the secondary (stepped down) voltage as the second number. For example, 480:120 represents the ratio of a PT that steps down

480 volts to 120 volts.

Drawing 8 represents a PT, using black dots to show the phase/polarity reference for the PT. A PT must be installed with the correct polarity reference or else all readings will be inaccurate.



Drawing 8.

Figure 2 shows a typical voltage measurement using a PT and a Moore Industries PAV Voltage Transducer. A likely application for this is monitoring voltage level on a motor or light when a threshold level of voltage must be maintained.

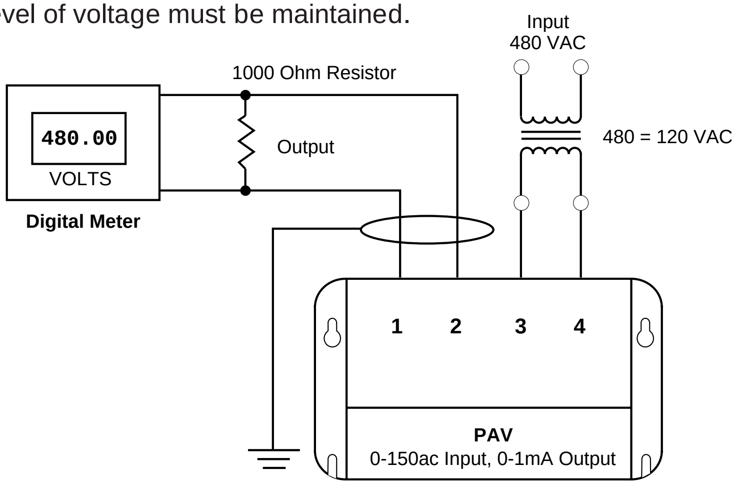


Figure 2.

Current Measurement

As in voltage measurement, current may be measured by the direct connect method or using a current transformer (CT) as a step down device. Figure 3, on the next page, shows the direct connect method with a current transducer.

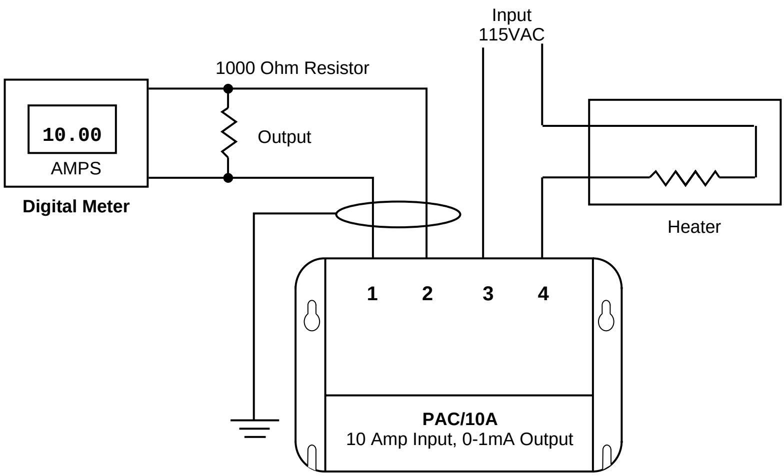
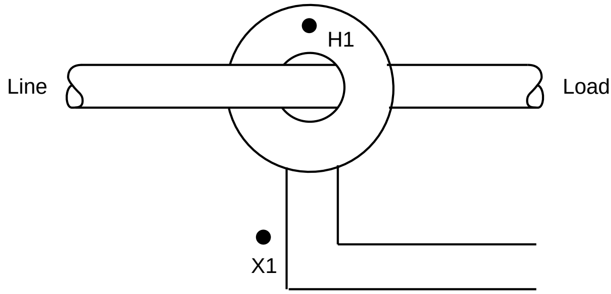


Figure 3.

Drawing 9 shows a CT used to step down the current on a power line. The black dots represent the phase/polarity reference of the CT (which indicates how the unit should be oriented when installed).

H1 (or the primary) of the CT should face toward the energy flowing from the line/source to the load. X1 (or the secondary) represents the high side of the secondary winding in the CT. Installing the CT in the correct orientation is essential to accurate measurements. If installed incorrectly, the CT will be “out of phase” with the line monitored, and all readings will be inaccurate.

Generally, the second number in a current transformer ratio is 5 amps. Typical ratios are 100:5 and 1000:5. The CT ratio equals H1:X1. Drawing 9.



Note: On current transformers the secondary winding must be connected at all times to an electrical load (i.e. transducer, meter, or protective device) or shorted. This is necessary to insure against the possibility of voltage build-up. Voltage build-up will occur, and present a personnel hazard, if the secondary winding is open circuited during primary current flow.

Figure 4 shows a CT used with our PAC Current Transducer to monitor a power line.

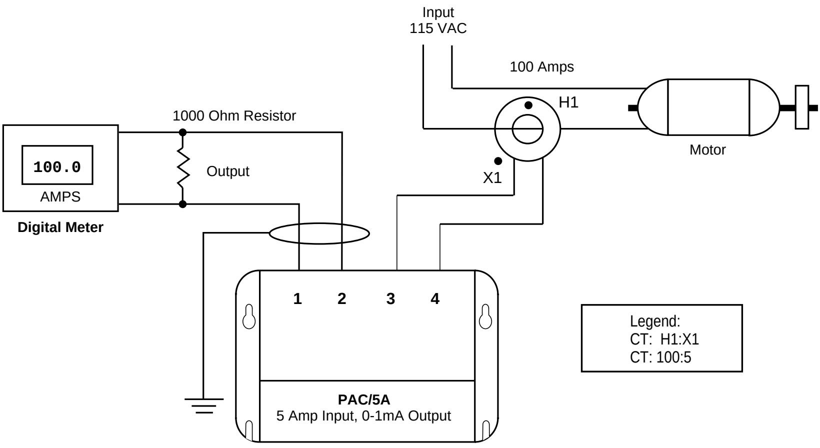


Figure 4.

VI. Taking Watt and VAR Measurements

This section integrates the various ac power systems and actual equipment used to make watt and VAR measurements. The techniques for measuring watts and VARs are similar, so we will use only watts in the following examples.

Single-Phase Two-Wire

As noted previously, a two-wire system requires one measuring element to determine power. You calculate the ac power in a single phase system using this formula:

Power = Voltage • Current • Power Factor
(or)
W = V • A • Cosø

An example of a correct model number for the a PWT Watt Transducer from Moore Industries configured for a single-phase two-wire system is:
PWT/120AC,5A/4-20MA/1E/-120AC[SM]

Figure 5 shows the PWT connected to a single-phase circuit using PTs and CTs.

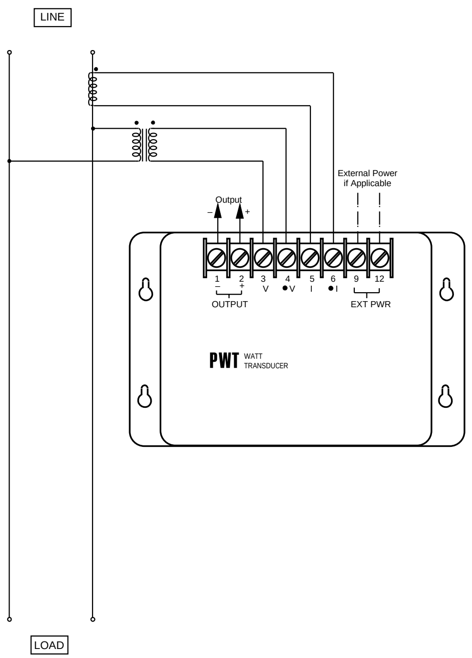


Figure 5.

Three-Phase Three-Wire

Measuring power on this type of system, the most common arrangement found in the process industries, requires a two-element transducer. As shown in Figure 6, the voltage on the third wire (B) functions as a reference for each of the transducer's elements.

An example model number for a two-element PWT Watt Transducer for this type of system is:

PWT/120AC,5A/4-20MA/2E/-120AC[SM]

Watts equal: $W = \sqrt{3} \cdot V \cdot A \cdot \cos Ø$

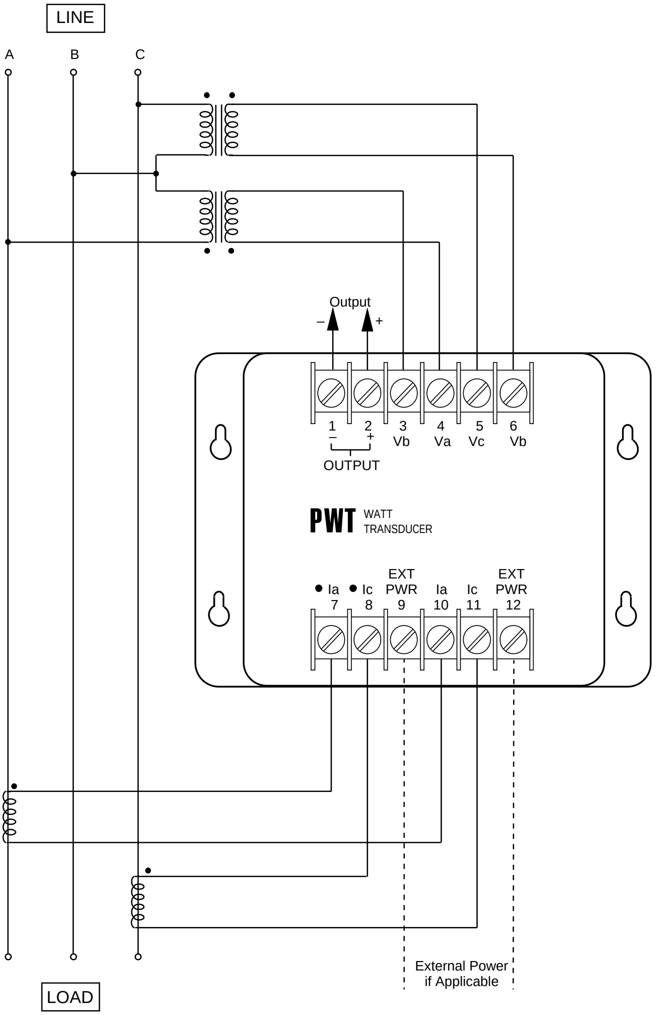


Figure 6.

Three-Phase Four-Wire

These circuits are best served by a three-element transducer, which provides optimum accuracy for both balanced and unbalanced conditions. The transducer reads all three voltages with respect to neutral and all three currents. The transducer sums the reading from all three elements to create an output representing total watts.

Figure 7 shows a Moore Industries PWT Watt Transducer connected to a three-phase four-wire circuit, using PTs and CTs. An example model number for this application is:

PWT/120AC,5A/4-20MA/3E/-120AC[SM]

Watts equal:

W = 3 • V • A • CosØ

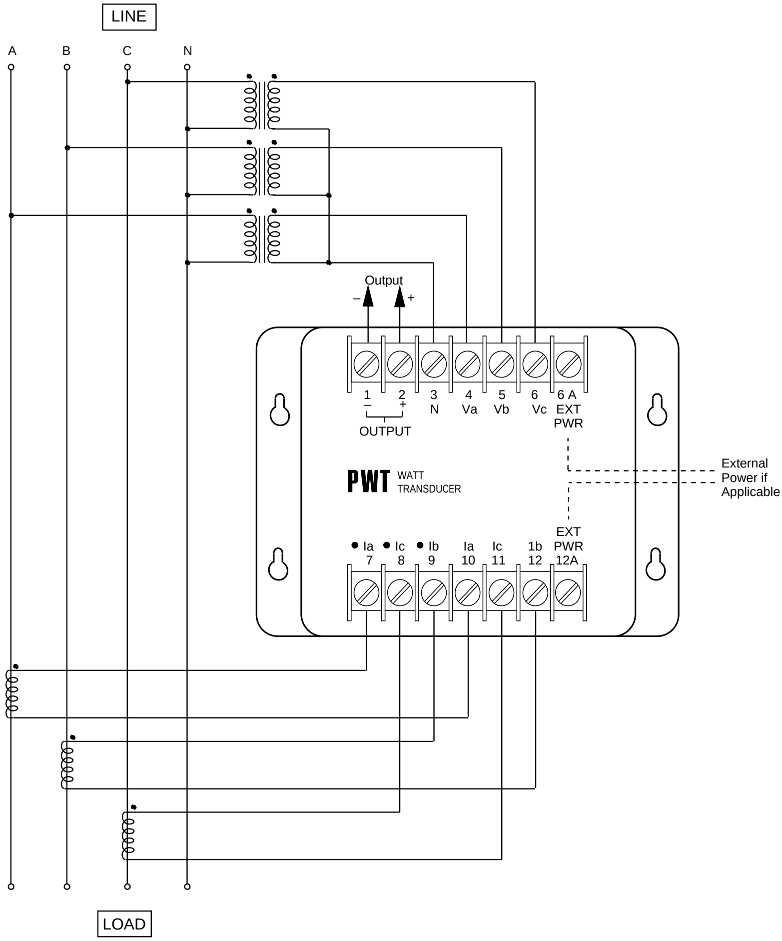


Figure 7.

Another way to measure a three-phase four-wire system is with a 2-1/2 element transducer, but some accuracy will be sacrificed if the system is not completely balanced. A 2-1/2 element transducer uses all three current and only two voltage inputs.   About the only facility which might have balanced loads is a utility transmission site. (Unbalanced loads result from the variations in load drawn by equipment on the various phases of the circuit.)

Figure 8 shows a Moore Industries PWT 2-1/2 element transducer connected to a balanced three-phase four-wire circuit. An example model number for this unit is:

PWT/120AC,5A/4-20MA/2.5E/-120AC[SM]

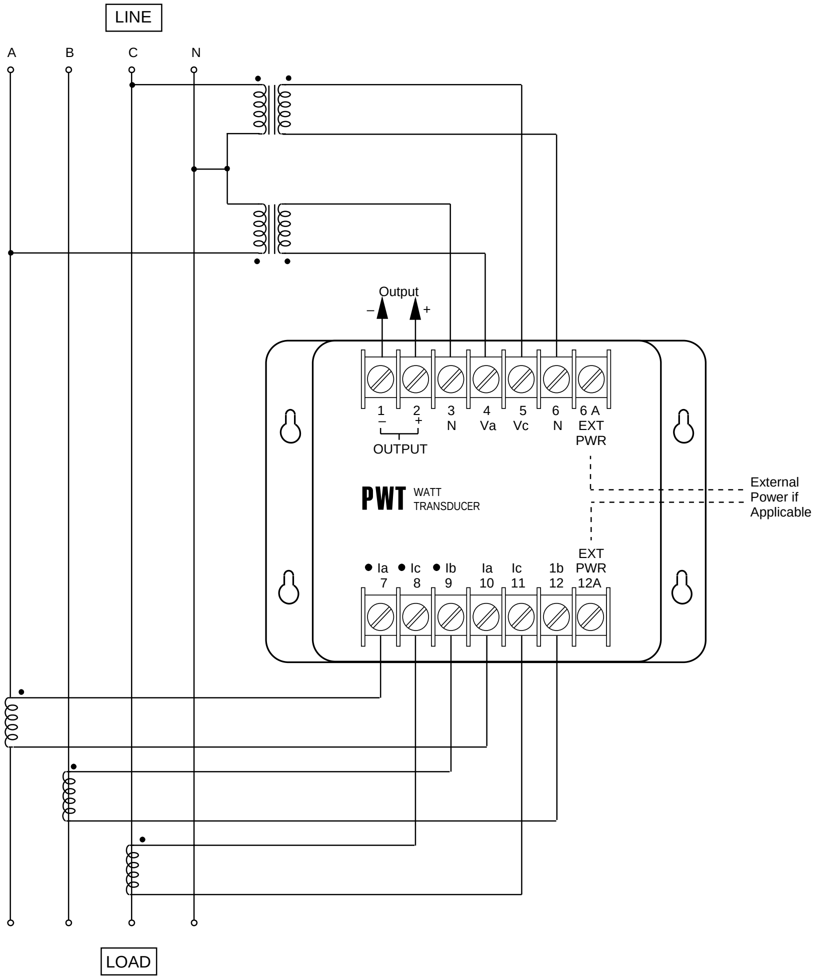


Figure 8.

This matrix shows some typical applications for power transducers:

Transducer	# of Elements	Type of Circuit	Typical Applications
PWT Watt	1	1-phs 2-w	Heating elements, Convenience outlets
PWT Watt	1-1/2	3-phs 3-w	Single motor load
PWT Watt	2	3-phs 3-w pumps	Motors, conveyors
PWT Watt	2-1/2	3-phs 4-w	Balanced circuit
PWT Watt	3	3-phs 4-w	Factory substation
PAC Current	1	1-phs	Phase current
PAV Voltage	1	1-phs	Phase voltage

VII. Glossary

Ampere—A unit of electrical current or rate of flow of electrons. One volt across one ohm of resistance causes a current flow of one ampere. A flow of one coulomb per second equals one ampere.
Apparent Power—The product of voltage and current in a circuit in which the two reach their peaks at different times, or, in other words, there is a phase angle between voltage and current. Units are VA.

Balanced load—An alternating current power system consisting of more than two current-carrying conductors in which these current-carrying conductors all carry the same current.
Billing demand—The demand level which a utility uses to calculate the demand charges on the current month's bill. If the rate schedule includes a ratchet clause or minimum demand charge, billing demand may or may not be the actual average demand for the current month.
Burden—The electrical load an instrument or meter places on a current or potential transformer. All current and potential transformers have a rated burden which should not be exceeded or the transformer accuracy will deteriorate.

Capacitor—A device consisting essentially of two conducting surfaces separated by an insulating material or dielectric such as air, paper, mica, plastic, film, or oil. A capacitor stores electrical energy, blocks the flow of direct current, and permits the flow of alternating current to a degree dependent upon the capacitance and frequency.
Capacitive Reactance—Component of impedance due to capacitance. Symbol is "X_C."
Clamp-on CT—A current transformer which clamps around a current-carrying conductor so that the conductor does not have to be opened for insertion of the transformer primary. Particularly suited for making energy surveys where current must be sensed at many points for relatively short periods.
Connected load—The total load which a customer can impose on the electrical system if everything is connected at one time. Connected load can be measured in horsepower, watts, or volt-amperes. Some rate schedules establish a minimum demand charge by imposing a fee per unit of connected load.

Contract load capacity—A load capacity contracted with a utility and related to connected load. The minimum monthly demand charge is sometimes established by applying the demand rate to some specified percentage of the contracted capacity.

Coulomb—The unit of electric charge equal to the quantity of electricity transferred by a current of one ampere in one second.

Current Transformer (CT)—An instrument transformer, intended for measuring or control purposes, designed to have its primary winding connected in series with a conductor carrying the current to be measured or controlled. Also see clamp-on CT, where the conductor itself acts as the primary. CT's step down high currents to lower values which can be used as input signals to measuring instruments. They must be used with caution.

Current transformer ratio–The ratio of primary amperes divided by secondary amperes.

Demand—A measure of the customer load connected to the electrical power system at any given time. Units are usually watts or volt-amperes.

Demand-hours—The equivalent number of hours in a month during which the peak average demand is fully utilized. In other words, if energy consumption for the current month is X kwhr and the peak average demand is Y kw, then the demand-hours is equal to X/Y hours.

The higher the number of demand-hours the better the demand leveling situation and the more efficiently demand is being used. Many rate schedules have demand-hour based energy rate breaks where the higher the demand-hour figure the lower the energy consumption rate in $/kwhr.

Demand interval—Demand charges are based on peak average demand over a utility-specified time interval, not on the instantaneous demand (or connected load) at any given moment. This period of time is called the demand interval. Demand intervals typically range from 15, 20, to 30 minutes, although they can drop as low a five minutes.

Demand-utilization efficiency—Related to demand-hours and really a measure of how successful demand leveling procedures have been. Calculated by dividing demand hours by 720, the number of hours in a 30 day billing period. Although demand-utilization efficiency heavily depends on the type of facility, in general an efficiency of 50% is considered average, 40% and lower poor, and 60% and higher good.

Discretionary loads—Loads which may be removed from the line for short periods of time without affecting business, plant operation, or personnel comfort. Typical are HVAC systems, hot water heaters, and snow-melt systems. These types of load provide the shed/restore capability required in power demand controller systems.

Efficiency—In general, the ratio of output power to input power expressed as a percentage. For electromechanical equipment, such as motors, it is very difficult to determine true efficiency under plant floor conditions. Electric input power can be easily measured, but accurately determining mechanical output power is difficult.

Energy consumption charges—The charges a utility imposes for the consumption of real power in watts. Units are usually dollars per kilowatt-hour.

Fuel-adjustment charges—Charges from a utility for changes in the cost of the fuel they use and other utility-cost factors. Frequently these charges are based on complex formulas which include many variables related to the cost of delivering electrical energy. Units are usually $/kwhr.

Frequency—The number of recurrences of a periodic phenomenon in a unit of time. In electrical terms, frequency is specified as so many Hertz (Hz) where one Hz equals one cycle per second.

Horsepower (hp)—A unit of power, or the capacity of a mechanism to do work. It is equivalent to raising 33,000 pounds one foot in one minute. One horsepower equals 746 watts.

Inductive Reactance—Component of impedance due to inductance. Symbol is “X_l.”

Impedance—The total opposition (i.e. resistance and reactance) a circuit offers to the flow of alternating current at a given frequency. It is measured in ohms.

Induction motor—An alternating current motor in which the primary winding (usually the stator) is connected to the power source and induces a current into a polyphase secondary (usually the rotor). Induction motors are the principal source of poor power factor problems.

Inductor—Also called an inductance or retardation coil. A conductor, wound into a spiral or coil to increase its inductive intensity, is used for introducing inductance into a circuit. An inductor retards the change of current flow through it.

Initiator pulses—Electrical impulses generated by pulse-initiator mechanisms installed in utility revenue meters. Each pulse indicates the consumption of a specific number of watts. These pulses can be used to measure energy consumption and demand.
Installed load—Equivalent to connected load.

Joule—Unit of measure. One joule of work is accomplished when a voltage of one volt causes one coulomb of electrons to pass through a circuit.

Kilowatt-hour (kwhr)—A unit of electrical measurement indicating the expenditure of 1,000 watts for one hour. Higher quantities are expressed in megawatt hours, or the expenditure of one million watts for one hour.

Lagging current—The current flowing in a circuit which is mostly inductive. If a circuit contains only inductance the current lags the applied voltage by 90°. Lagging current means lagging power factor of less than unity.
Leading current—The current flowing in a circuit which is mostly capacitive. If a circuit contains only capacitance the current leads the applied voltage by 90°. Leading current means leading power factor of less than unity.
Load—Any device or circuit which consumes power in an electrical system.
Load restoring—The energization of loads that were previously removed from the line to limit the load and control demand level.
Load shedding—The removal of loads from the line to limit load and control demand level.

Neutral—The conductor chosen as the return path for the current from the load to the source in power measurement procedures. The neutral is frequently, but not necessarily, grounded.

Ohm—The unit of electrical resistance. One ohm is the value of resistance through which a potential difference of one volt will maintain a current flow of one ampere.
Ohms' Law—The voltage across an element of a direct current circuit is equal to the current in amperes through the element multiplied by the resistance of the element in ohms.

Peak average demand—The highest average load over a utility-specified time interval during a billing period. If there is no ratchet clause in the rate schedule then the peak average demand is also the billing demand.

Polyphase—Having or utilizing several phases. A polyphase alternating current power circuit has several phases of alternating current with a fixed phase angle between phases.

Potential transformer (PT)—An instrument transformer of which the primary winding is connected in parallel with the circuit whose voltage is to be measured or controlled. PT's normally are used to step down high voltage potentials to levels acceptable to measuring instruments.

Potential transformer ratio—The ratio of primary voltage divided by secondary voltage.

Power demand controllers—Control devices designed to minimize and level average demand by maintaining it below some pre-selected level. This is normally accomplished by shedding and restoring discretionary loads. There are many basic principles of operation of power demand controllers.

Power factor—The ratio of real power (in watts) of an alternating current circuit to the apparent power in volt-amperes. Also the cosine of the phase angle between the voltage applied to a load and the current passing through it.

Power factor correction—Steps taken to raise the power factor by bringing the current more nearly in phase with the applied voltage. Most frequently this consists of increasing the lagging power factor of inductive circuits by adding capacitance.

Power factor penalty—The charge utilities impose for operating at power factors below some rate-schedule-specified level. This level ranges from a lagging power factor of 0.80 to unity. Utilities calculate power factor penalties in countless ways.

Pulse initiator—An assemblage added to a revenue meter which generates pulses proportional to meter disk rotation. Each pulse represents a discrete quantity of energy consumed. Most frequently the pulses are generated photoelectrically and output through mercury-wetted relays.

Q—A phantom quantity used by power companies to calculate volt-ampere-reactive (VAR) when there are both leading and lagging power factors. A Q-hour meter will determine VAR-hr's when the power factors vary from 30° leading to 90° lagging.

Q-hour meter—Similar to a watt-hour meter except that the voltage applied to each potential coil lags the voltage supplied to the respective watt-hour meter potential coil by 60°. This is generally accomplished by cross-phasing, thus eliminating the need for a phase-shifting transformer. The VAR-hr information can be calculated as follows: VAR-hr= (2Q hr - whr)/ sqrt3

Ratchet clause—A rate schedule clause which states that billing demand may be based on current month peak average demand or on historical peak average demand, depending on relative magnitude.

Usually the historical period is the past eleven months, although it can be for the life of the contract. Billing demand is either the current month's peak average demand or some percentage (75% is typical) of the highest historical peak average demand, depending on which is largest.

Reactance—The opposition to the flow of alternating current. Capacitive reactance is the opposition offered by capacitors and inductive reactance is the opposition offered by an inductive load. Both reactances are measured in ohms.

Reactive power—Also called a watt-less power and measured in volt-amperes-reactive. Reactive power increases with decreasing power factor and is the component of apparent power which does no real work in a system.

Real power—The component of apparent power that represents true work in an alternating current circuit. It is expressed in watts and is equal to the apparent power times the power factor.

Resistance—The property of a substance which impedes current flow and results in the dissipation of power in the form of heat. The unit of resistance is the ohm. One ohm is the resistance through which a difference of potential of one volt will produce a current of one ampere.

Revenue meter—A meter used by a utility to generate billing information. Many types of meters fall in this category depending on the rate structure.

Root mean square (RMS)—The effective value of alternating current or voltage. The RMS value of voltage and current can be used for the accurate computation of power in watts. The RMS value is the same value as if continuous direct current were applied to a pure resistance.

Single-phase—An alternating current circuit in which only one phase of current is available in a two-conductor or three-conductor system where the load lines are 0° or 180° out of phase.

Sliding demand interval—A method of calculating average demand by averaging the demand over several successive short time intervals, advancing one short time interval each time. Updating average demand at short time intervals gives the utility a much better measure of true demand and makes it difficult for the customer to obscure high short-term loads.

Subsidiary billing factors—Secondary billing factors in a rate schedule, including such things as fuel-adjustment costs, multiple metering points, interruptible service provisions, and transformer ownership benefits.

Time-dependent clauses—Rate schedule provisions which vary rates depending on the time of day or time of year when energy is consumed. Frequently these clauses cover both demand and energy charges. There is money to be saved by operating high loads and consuming high amounts of energy during off-peak periods when rates are lower.

True power—Same as real power.

Unbalanced loads—A situation existing in an alternating current system using more than two current-carrying conductors where uneven loading of the phases results in unequal current in the current-carrying conductors.

Volt-ampere (VA)—The unit of apparent power. It equals volts x amperes, regardless of the power factor.

Volt-ampere demand—Where peak average demand is measured in volt-amperes rather than watts. In this case the customer is automatically penalized for operating at any power factor less than unity.

Volt-ampere-reactive (VAR)—The unit of reactive power, as opposed to real power, in watts. One VAR is equal to one reactive volt-ampere.

Volt-ampere-reactive demand—Measuring VAR demand is a method of penalizing for poor power factor. Multiplying by some rate ($/VAR) penalizes for operating at any power less than unity.

Frequently there is a quantity of “free” VAR which is determined as some percentage of the peak average watt demand. All excess VAR over this quantity is then billed at this $/VAR rate. Effectively, this penalizes for operating below some specified power factor less than unity.

Volt-ampere-reactive-hour—The measure of the number of VAR's used in one hour. VAR-hr and whr are frequently used to calculate average power factor during a billing period.
Voltage (V)—The force which causes current to flow through a conductor. One volt equals the force required to produce a current flow of one ampere through a resistance of one ohm.

Watt (W)—A measure of real power. The unit of electric power required to do work at the rate of one joule per second. It is the power expended when one ampere of direct current flows through a resistance of one ohm.
Watt demand—The usual demand billing factor where peak average demand is measured in watts or real power.
Watt-hour (whr)—A unit of electrical work indicating the expenditure of one watt of electrical power for one hour.
Wattmeter—An instrument for measuring the real power in an electric circuit. Its scale is usually graduated in watts, kilowatts, or megawatts.

VIII. Reference Charts and Information

A. Transducer Output Calculations

Most transducers you need will be standard calibration units. How then, do you determine what the output represents for both potential and current transformers?

The output of a transducer represents the standard calibration of the unit (from the data contained within the Specifications section on the unit's data sheet) multiplied by the transformer ratios. You determine the output with this formula:

Transducer Cal x Potential Transformer Ratio x Current Transformer Ratio

Standard Transducer Calibrations

Example 1: You have a 480:120 ratio potential transformer, 100:5 ratio current transformer and are monitoring a three-phase three-wire system. For this example we will use a two element transducer.

The ratios show us that the secondary of the PT is 120 volts and the secondary of the CT is 5 amps. We therefore would use a 120 volt 5 amp input watt transducer. Looking to the Specifications section of the PWT Watt Transducer data sheet (table 4) with 120ac, 5a, we find the standard output would be 500 watts per element.

We can now determine what the output would represent by multiplying the transformer ratios by the full scale calibration of the transformer:

$$\text{500 WATTS PER ELEMENT} \times \text{2 ELEMENTS} \times \frac{480}{120} \times \frac{100}{5} = \text{80,000 WATTS}$$

This is what the output (i.e. 0-1mA) would equal (0-80,000 watts).

This type of calculation is true of any of the watt or VAR transducers. There will be rare times that the transducer will need to be custom calibrated to meet the customer's specific needs. An example of this would be if the customer had a meter already scaled to a specific value.

B. Full-Load Motor Currents

Use this chart to determine the full-load motor current of three-phase induction-type Squirrel Cage and Wound Rotor motors. Using the known horsepower of the motor (left column) and going across to the appropriate voltage (from the nameplate) you can estimate the motor current, in amps, at that voltage.

Motor Current in amps; Translating horsepower to voltage

hp	115V	200V	230V	460V	575V	2300V	4160V
0.5	4	2.3	2	1	0.8		
0.75	5.6	3.2	2.8	1.4	1.1		
1	7.2	4.15	3.6	1.8	1.4		
1.5	10.4	6	5.2	2.6	2.1		
2	13.6	7.8	6.8	3.4	2.7		
3		11	9.6	4.8	3.9		
5		17.5	15.2	7.6	6.1		
7.5		25	22	11	9		
10		32	28	14	11		
15		48	42	21	17		
20		62	54	27	22		
25		78	68	34	27		
30		92	80	40	32		
40		120	104	52	41		
50		150	130	65	52		
60		177	154	77	62	16	8.9
75		221	192	96	77	20	11
100		285	248	124	99	26	14.4
125		368	312	156	125	31	17
150		415	360	180	144	37	20.5
200		550	480	240	192	49	27

Over 200, appx. amps/hp

	2.75	2.4	1.2	0.96	0.24	0.13

C. Nameplate Voltage Ratings of Standard Induction Motors

Nominal System Voltage	Nameplate Voltage
Single-Phase Motors:	
120	115
240	230
Three-Phase Motors:	
208	200
240	230
480	460
600	575
2400	2300
4160	4000
4800	4600
6900	6600
13800	13200

Data taken from IEEE Std. 141-1976

D. Nominal System Voltages

The information on this page should correspond to the power your facility receives from the power company.

Nominal System Voltages			Maximum System Voltages
Single Phase Systems:			
Two Wire	Three Wire		
120AL	120/240		127 or 127/254
Three Phase Systems:			
	Three Wire	Four Wire	
		208Y/120	220
	(240)	240/120	254
	480	480Y/277	508
	(600)		635
	(2400)		2540
	4160		4400
	(4800)		5080
	(6900)		7260
		12470Y/7200	13200
		13200Y/7620	13970
	13800	(13800Y/7970)	14520
	(23000)		24340
		24940Y/14400	26400
	(34500)	34500Y/19920	36500
	(46000)		48300
	69000		72500

* Those system voltages shown without parenthesis are preferred. Taken from IEEE Std. 141-1976.

IX. Power Transducers Available from Moore Industries

PAC/PAV Ac Current/Voltage Transducers
Measures ac current or voltage drawn by a source of load, such as a motor or heater. This information can be used to to help schedule motor maintenance, monitor viscosity within a process, or record a machine's energy usage.

PDC Dc Voltage Transducer & Ground Fault Detector
Monitors ground faults on a battery back-up system to assure that energy doesn't leak to ground, thus draining the system and leaving it useless.

PVT, PWT, PWV Ac Power Transducers
These units monitor demand and power usage, from which revenue billing may be calculated.

PVW, PWH, PCV Ac Power/Energy Transducers
These units combine the function of the ac power transducers with an integrator(s) to provide contact output indicating energy (KW-hours, KVAR-hours).

SM Surface Mount Housing
Every unit comes in this style of housing, which is rust-free aluminum and has card guides running its entire depth to support the PC boards. Conforming to commonly accepted standards for wiring and footprint sizes makes this housing easy to install and work with.