SELECTING AND USING TRANSDUCERS

FOR THE MEASUREMENT OF ELECTRIC

POWER, VOLTAGE, AND CURRENT

SELECTING AND USING TRANSDUCERS
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PART I

TRANSDUCERS AND TRANSFORMERS FOR ELECTRICAL MEASUREMENTS

Transducers for electrical measurement are an essential part of any monitoring, measuring, or controlling system where electrical quantities are involved. In order to use these transducers it is important to know what they do, what kind of signal they provide, and how to connect them.

Part I provides an introduction in using voltage, current, and power (watt) transducers along with using potential and current transformers.

POTENTIAL TRANSFORMERS

Most manufactures' transducers accept up to a maximum of 600 volts AC direct. For AC voltages greater than 600 volts, potential transformers are required. Potential transformers are precision transformers that step the voltage down to 120 volts AC, a standard transducer input. These transformers, particularly when used with power or watt transducers, must be instrument grade transformers. They must not only be precise in stepping down the voltage but in maintaining the phase or time relationship of the voltage. This is very important. Do not attempt to save money by using control class transformers.

Transducer and meter loads are connected in parallel to the potential transformer. Take care not to exceed the transformer burden rating. This burden is expressed in VA for volt-amperes (the product of volts and amps).

Instrument Grade
Potential
Transformer

CURRENT TRANSFORMERS

For AC applications most manufacturers' transducers will not accept direct current input over 20 amperes. For higher amperages current transformers are utilized.

Instrument Grade
Current Transformer

These transformers are most often the 'donut' type. The current carrying conductor is passed through the opening or window of the 'donut.' The secondary winding of the current transformer is wound by the manufacturer on the toroidal iron core which makes the 'donut' shape. On most North American manufactured current transformers, the secondary is wound to produce 5 amperes when rated current is passed through the window. The turns ratio is expressed as 100:5 or 3500:5 (read as 100 to 5 and 3500 to 5). The first number represents the rated

full-scale primary current. The primary winding consists of the single pass of the current carrying conductor through the window. The second number represents the full-scale secondary current in amperes. A 100:5 ratio current transformer steps the current from 100 amperes down to 5 amperes. The 3500:5 ratio current transformer steps the current from 3500 amperes down to 5 amperes.

As with potential transformers, only use instrument grade current transformers with power measuring transducers.

Connect the loads on current transformers in series being careful not to exceed the burden rating. The phase angle shift introduced by current transformers is sensitive to the loading. Therefore, keep the burden to a minimum by using adequate size secondary leads and keeping secondary leads as short as possible.
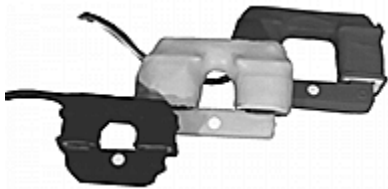

Split Core Current
Transformers

CAUTION:: Current transformers can and will develop a lethal voltage and possibly self destruct if the secondary is open when primary current is present! People have been hurt and equipment damaged when the secondary winding of a current transformer was opened. Never disconnect the secondary or leave it open when there is the possibility of primary current.

It is essential that experienced persons install current transformers. If you must make a connection to the current transformer while it is in use, SHORT THE SECONDARY WINDING before doing anything. Some current transformers have a shorting block for this purpose. Auxiliary shorting blocks are available for this purpose too.

Current transformers are rated for the voltage class for which they are to be used. These classes are: 600 volts, 5000 volts, 8700 volts, 15 kilovolts, 25 kilovolts, and 34.5 kilovolts. Make certain that the current transformers are rated for the voltage with which they are working or that the conductor is insulated for the class voltage. Current transformers being used on conductors with voltages greater than 600 volts must have the secondary grounded to an earth ground.

VOLTAGE TRANSDUCERS
Voltage transducers provide a DC current or voltage output directly proportional to the AC input voltage. AC voltage transducers typically have a transformer input to isolate the transducer from the voltage input. Following the transformer are the electronics.
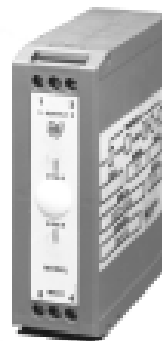
DIN Rail Mount
Voltage Transducer

There are two types of AC voltage transducers.

- Absolute average measuring, rms calibrated (or mean value measuring, rms calibrated).

  These inexpensive transducers simply convert the AC input to DC and have the output calibrated to represent the root mean square (RMS) value for sine wave input. This type is very adequate for situations in which the voltage wave shape is not distorted. Any odd harmonic or discontinuity will introduce large error. Use the true RMS measuring type when distortion of a sine wave is present.

True RMS Measuring Voltage Transducer

- True RMS (Root Mean Square) measuring.

  These transducers calculate the RMS value of the voltage input and provide a DC output directly proportional to the effective value of the voltage input. This type should be used whenever the voltage is distorted.
  Transducer models are available for nominal input voltages of 69, 120, 240, and 480 volts. These typically have a measuring range of 0 to 125%

of the nominal input rating. Thus, a 120-volt model has a range of 0 to 150 volts. For voltage input higher than 600 volts, one should use a potential transformer.

CURRENT TRANSDUCERS

Current transducers provide a DC current or voltage output directly proportional to the AC input current. AC current transducers typically have a transformer input to isolate the transducer from the current input. Following the transformer are the electronics.

Split Core Average Absolute Measuring, RMS Calibrated Current Transducer

There are two types of AC current transducers.

- Absolute average measuring, rms calibrated (or mean value measuring, rms calibrated).

  These inexpensive transducers simply convert the AC input to DC and have the output calibrated to represent the root mean square (RMS) value for sine wave input. This type is very adequate for situations in which the current wave shape is not distorted. Any odd harmonic or discontinuity will introduce large error. Use the true RMS measuring type when distortion of a sine wave is present.

- True RMS (root mean square)
  measuring.
  These transducers calculate the RMS
  value of the current input and provide
  a DC output directly proportional to
  the effective value of the current
  input. This type should be used
  whenever the current is distorted.

Ohio Semitronics, Inc. has a wide range of
models available for various situations.
Models are available with or without current
transformers, with current transformers built
in, and with split core current transformers.

**True RMS
Measuring
Current
Transducer.**

POWER OR WATT TRANSDUCERS
A watt or power transducer measures true
electrical power delivered to a load and
converts that measurement to a DC voltage
or current signal proportional to the power
measured.

To measure power, the watt transducer must
monitor both the voltage and current in a
circuit. Further, it must be able to accurately
determine the phase relationship between the
voltage and current. This is the angle by
which the current leads or lags the voltage.
This measurement is very important to
accurately determine true power.

UL Listed Watt Transducer

The watt transducer must also measure the
power in each of the branches of the circuit.
Your house, apartment, or small office is
wired in what is often referred to as the
Edison system. This is a three-wire, single-
phase system with two power lines and a
neutral. The watt transducer must measure
the power in each of the power lines or
mains. This circuit requires a two-element
watt transducer. A two-element watt
transducer has two-watt transducers in the
same case. The outputs of the two
transducers or multipliers are summed so that
the output signal of the entire watt transducer
represents total power. One, two, and three
element watt transducers are discussed in
Part II.

What type of watt transducer to use?

- Analog watt transducers including Hall
  effect provide good accuracy even with
  distorted wave shapes, discontinuity, or
 where there is poor frequency
  regulation.

PC5 Hall Effect Watt Transducer

- Electronic watt transducers with sampling or pulse-width, pulse-height type multipliers provide excellent accuracy but may have problems with discontinuity or where there is poor frequency regulation.

Before ordering watt transducers it is to your advantage to assess your specific needs and conditions, then check with your sales representative at Ohio Semitronics, Inc. if you have any questions.

Single-Phase Watt Transducers

The most common application for a watt transducer is monitoring a single-phase load such as a heater element or small motor. This requires a single element watt transducer connected directly between the power line and the load as illustrated below.
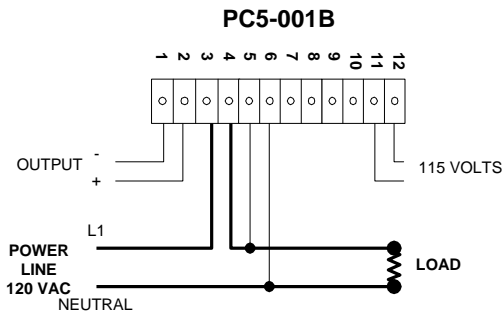
The single-phase watt transducer shown above has a single multiplier or element inside the electronics package.

Often the combined loads of an entire house, apartment, or office are monitored with a watt transducer. This requires a two-element model with current transformers. The two-element, single-phase watt transducer is connected as shown below.
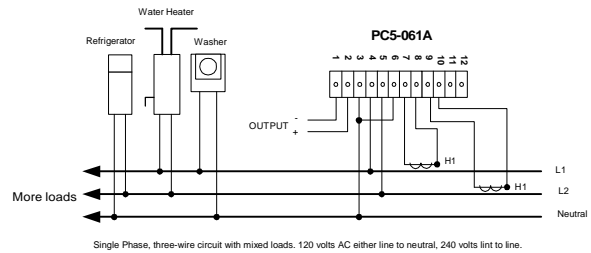
The two-element watt transducer shown above has two multipliers inside the electronics package. The output of these two multipliers is summed to obtain the total power. The output signal of this watt transducer thus represents the total power being used.

Three-Phase Watt Transducers

Most motors in industry are three-phase, three-wire motors. These require two-element watt transducers. Do not attempt to save money and use a single element transducer — it will not provide correct or useful information. Smaller three-phase motors may be connected directly to the watt transducer. Larger three-phase motors will require the use of current and/or potential transformers. All three cases are shown in the three diagrams that follow.

PC5-005B

0 to 1 mADC proportional to 0 to 2000 watts.

−

+

115 volts AC

Small 3 phase motor

L1 — 208 volts
L2 — 0 to 5 amps
3-phase, 3-wire.
L3

PC5-006B with 600:5 current transformers.

0 to 1 mADC proportional to 0 to 4000 watts X 600/5 or 480 kilowatts.

115 volts

3-phase, 3-wire Motor

X1   X1
H1
600:5
L1 — 480 volts
H1
L2 — 0 to 600 amperes
600:5
3-phase, 3-wire
L3

PC5-004B with 400:5 current transformers and 4200:120 potential transformers.

0 to 1 mADC proportional to 0 to 1000 watts X 400/5 X 4200/120 or 2,800 kilowatts.

−

+

115 volts AC (Could tap off PT)

3-phase, 3-wire Motor

X1 X1
H1 H1   X1
H1 X1
400:5
L1 — 4160 volts
H1
L2 — 0 to 400 amperes
400:5
3-phase, 3-wire
L3

Factories and large stores are typically supplied with three-phase, four-wire power. Heavy loads such as motors are connected line-to-line in a three-phase, three-wire configuration and lighter loads are connected line to neutral. Three element watt transducers are required to monitor the entire facility. This requires the use of current transformers. The connections are shown below.

GW5-007B

1 2 3 4 5 6 6A 7 8 9 10 11 12 12A

0 to 1 mADC proportional to 0 to 1500 watts X 600/5 or 180 kilowatts.

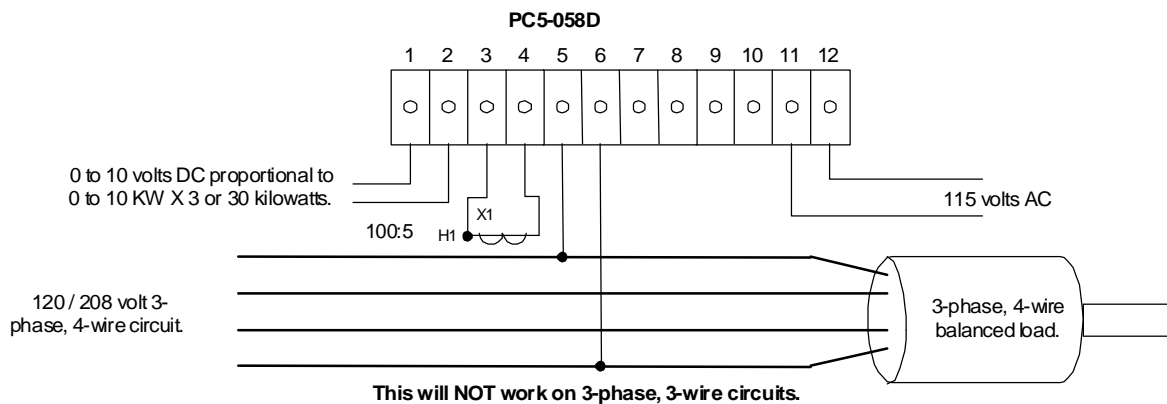115 volts AC

Motor loads connected line to line

Office machinery and lights connected line to neutral.

M

X1 600:5 H1

X1 600:5 H1

X1 600:5 H1

L1

L2

L3

Neutral
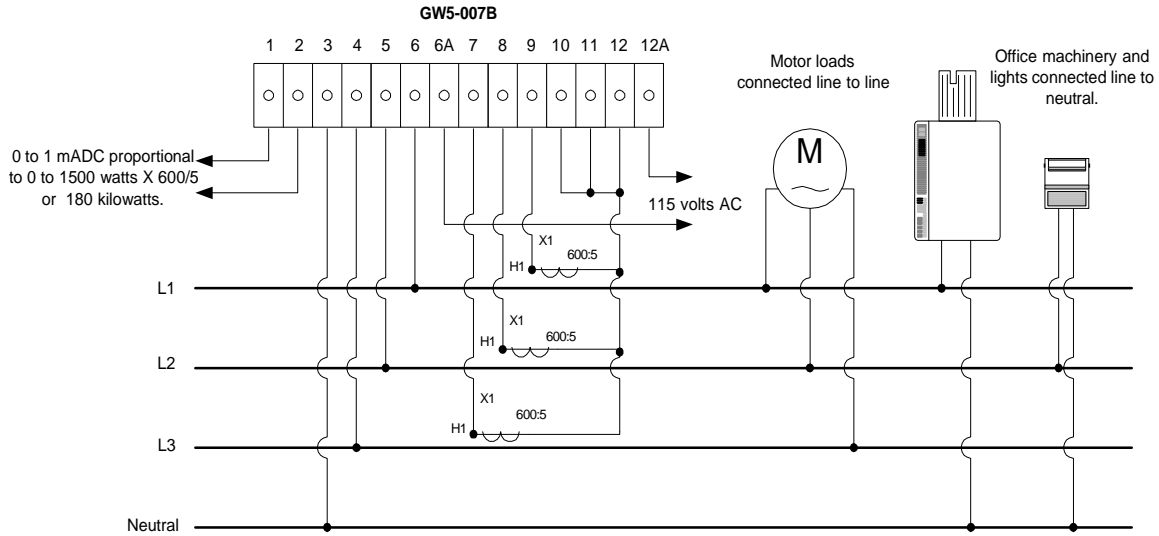
In special cases where a three-phase, four-wire load is known to be balanced in load and voltage, a single element watt transducer may be used to give an indication of total power by multiplying the value represented by the transducer output by three.

PC5-058D

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

0 to 10 volts DC proportional to 0 to 10 KW X 3 or 30 kilowatts.

115 volts AC

100:5 H1 X1

120 / 208 volt 3-phase, 4-wire circuit.

3-phase, 4-wire balanced load.

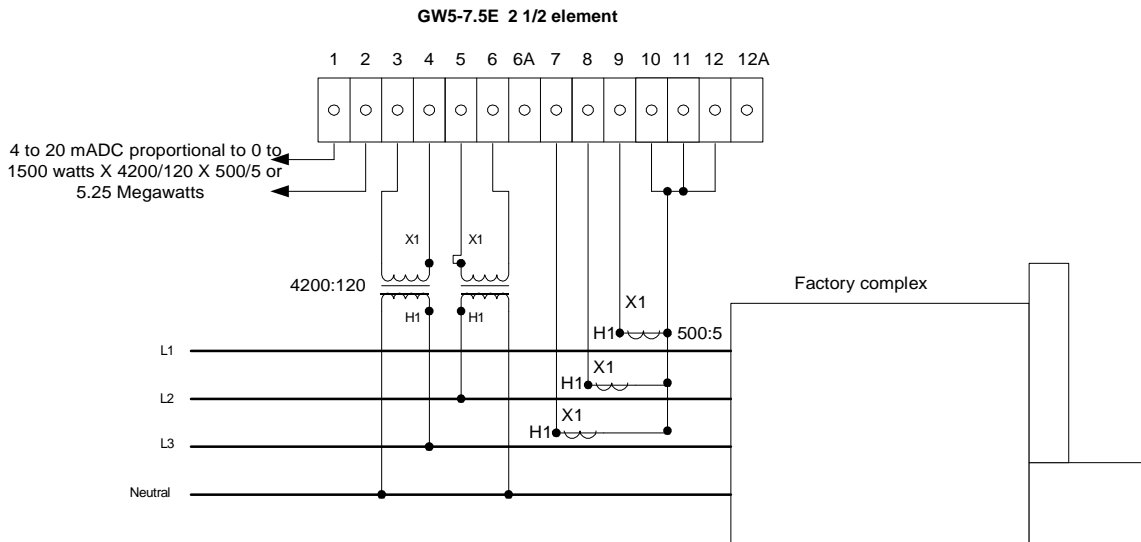**This will NOT work on 3-phase, 3-wire circuits.**

Wye Connected Motor.

Do not use this on a delta-connected motor.

The 2 ½ Element Watt Transducer

Monitoring three-phase, four-wire systems frequently involves using potential transformers. These transformers can cost much more than the watt transducer. To reduce cost, two potential transformers instead of three are used. The watt transducer from the two voltages can derive the third voltage.

GW5-7.5E 2 1/2 element

1   2   3   4   5   6   6A   7   8   9   10   11   12   12A

4 to 20 mADC proportional to 0 to 1500 watts X 4200/120 X 500/5 or 5.25 Megawatts

X1   X1

4200:120

H1   H1

X1

Factory complex

H1   500:5

X1

H1

X1

H1

L1

L2

L3

Neutral

Output Signals From Transducers

The voltage, current, and watt transducers discussed above are available with DC current or voltage output. The least expensive and simplest voltage and current transducers are available only with a current output.

How are these outputs used?

The most common is for metering. The transducer output is driving either an analog or digital meter. The use of either is simple.

Analog Meter

If you are using an analog meter, buy transducers that are supplied with a 0 to 1 mADC output and a 0 to 1 mADC meter movement. The meter supplier can scale the meter face to match the transducer range. Some examples are shown below.
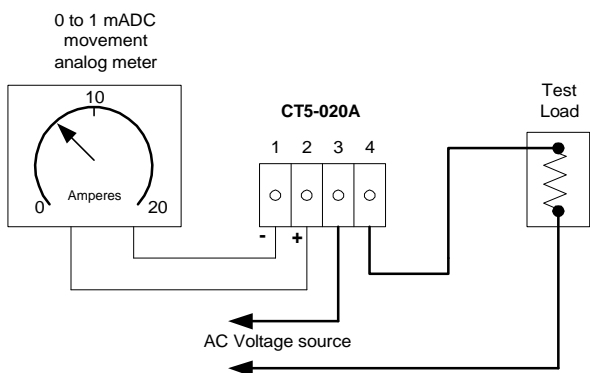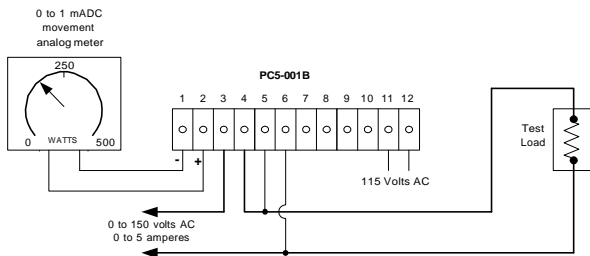
Digital Meter

Some digital meters allow the user to scale the meter to display to the transducer range. If you use one of these meters with a watt transducer that has a 4 to 20 mADC output representing 0 to 960 kilowatts, simply adjust the meter to read 0 at 4 mADC and 960 at 20 mADC.

If you are using a 0 to 2 volt DC input meter that does not allow scaling, use a scaling resistor. Some examples are shown below.
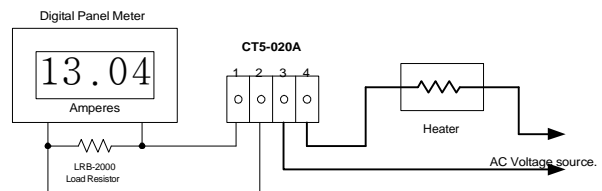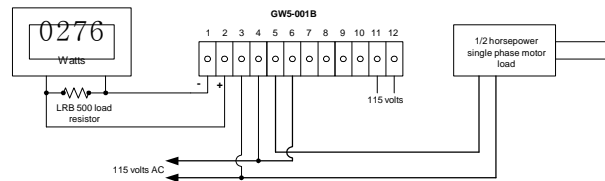
In both examples a 2-volt DC digital meter is being used. By applying Ohm's Law (R=E/I, the value of the resistor equals the voltage divided by the current.) one can determine the value of the resistor required. Remember that the output of the transducer is in milliamperes, 1/1000 of an ampere.

SELECTING AND USING TRANSDUCERS

How did we figure the value of the resistor?

Always base the resistor on the rated output of the transducer, the rated output is the wattage level or current value that is represented by 1 mADC.

In the first example the rated output of the transducer is 1000 watts. We would like the digital meter to read 1000. If we supply 1 volt to the meter, it will read 1.000.

Digital meter manufacturers build their meters so that the decimal point can be moved. This is done using wire jumpers on the connection strip of the meter, by DIP switches on the meter, or by wire jumpers or foil jumpers that the user cuts. Follow the meter manufacturer's instructions. In our example set the meter to display 1000 or 1000.0 when 1 volt is applied.

How did we get the 1-volt from the transducer? Use Ohm's law. The value of the resistor equals the desired voltage divided by the current. Or for our example, R=1/0.001 or 1000. Use of a 1000 Ω resistor will provide 1 volt at full scale of 1 mADC. Our meter will read 1000 for 1000 watts.

If you have questions regarding proper selection of a scaling resistor, call Ohio Semitronics, Inc. The OSI sales engineers or staff personnel will be glad to assist you.

In the second example we used a twenty-ampere current transducer with a digital meter. We want the meter to read 19.99 at full scale to take advantage of the four digits. (A 3-½ digit meter will read to 1.999 volts. Above this it will flash at you to let you know that the meter is over ranging.)

How do we get 2 volts?

Again use Ohm's Law. The value of the resistor will be R=2/0.001 or 2000 Ω. Set the decimal point so that the meter will read 19.99 at 1.999 volts. Your meter is now scaled to match the transducer.

Ohio Semitronics, Inc. manufactures precision load resistors for use with transducers. These are the LRB series Load Resistors. The load resistors are temperature compensated to maintain the accuracy of the electronic watt transducers.

Other Output Signals Available

Most transducers manufacturers have transducers available with 0 to 1 mADC, 0 to 5 volts DC, 0 to 10 volts DC, or 4 to 20 mADC outputs. The 0 to 10 volt and 0 to 5 volt outputs are typically (but not exclusively) used with data acquisition equipment, strip chart recorders, analog input cards for computers, or control interface devices.

The 4 to 20 mADC output is used with process control equipment, for long (over 200 feet) transmission of the signal, and frequently as a 'fail safe' monitoring of the signal.

If the watt transducer output is 4 mADC then one knows that the power being monitored is zero. However, if the output signal is zero, something is wrong — the transducer may have failed or it may have lost instrument power. The user can take corrective action.

Cables for Analog Signals

Ohio Semitronics, Inc. recommends using a shielded twisted pair of 22 gauge or larger wire to conduct an analog voltage or current signal from the transducer to the meter or instrument. If you are using a 1-mADC-output transducer and a load resistor, we recommend putting the load resistor on the meter or instrumentation package. Ground the shield at the receiving end only. Do not ground at both ends. Doing so can cause severe problems. I have known the shields to melt when a lightening strike has occurred nearby.

```
 ┌──────────────┐
 │   0276       │
 │     Watts    │
 └──────────────┘
       ───/\/\/\───  LRB 500 load
                     resistor

       Shielded twisted pair. Ground at meter or
       instrumentation end only.

              GW5-001B
```

1	2	3	4	5	6	7	8	9	10	11	12
○	○	○	○	○	○	○	○	○	○	○	○
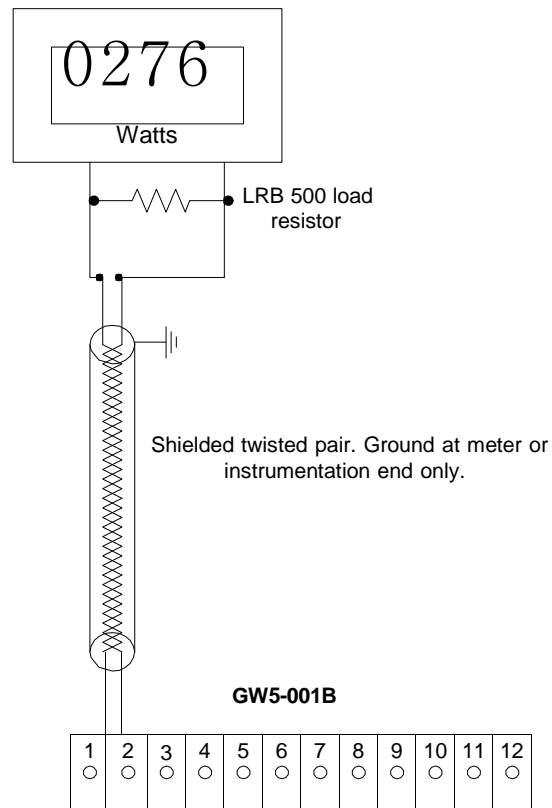
EXAMPLES OF POWER, VOLTAGE, AND CURENT MONITORING

Monitoring voltage, current, and power delivered to a test load. In this application a refrigerator is being examined.
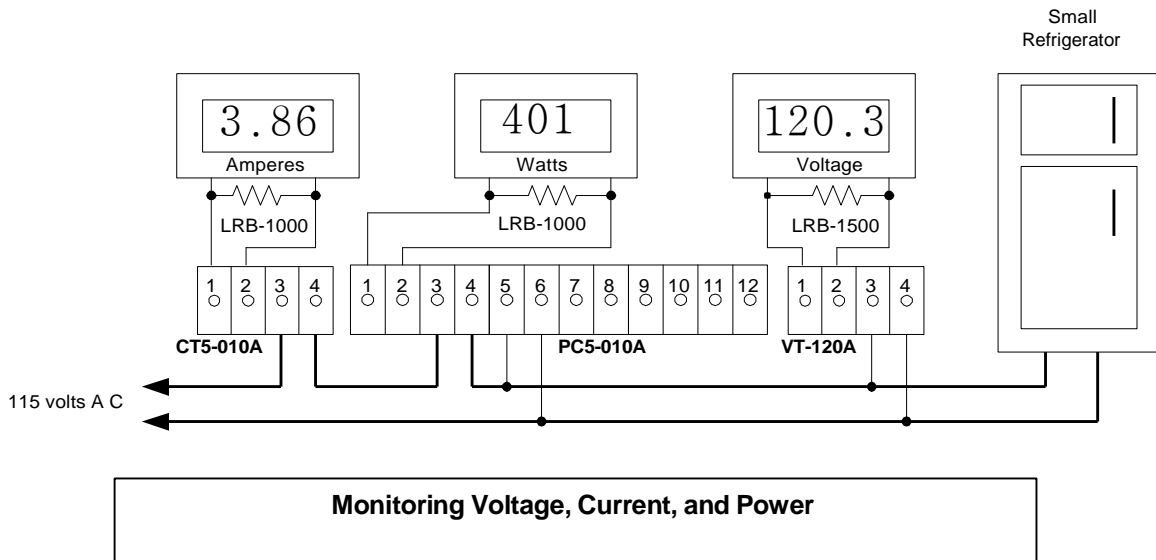Transducers used:
- CT5-010A current transducer is wired in series with the load.
- VT-120A voltage transducer is wired in parallel with the load.
- PC5-010A is wired in series with the load for monitoring the current and in parallel with the load for monitoring the voltage.

These are used as examples. Other transducers that may be used include the multifunction board level transducer PTB. This board provides analog outputs proportional to each phase of true RMS Current, each phase of true RMS voltage, and total power.

This example uses digital meter which are scaled using precision load resistors.

Small
Refrigerator

3.86
Amperes

401
Watts

120.3
Voltage

LRB-1000   LRB-1000   LRB-1500

| 1 | 2 | 3 | 4 | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | | 1 | 2 | 3 | 4 |

CT5-010A   **PC5-010A**   **VT-120A**

115 volts A C

Monitoring Voltage, Current, and Power

Load resistors are selected as follows:

- Remember Ohm's Law: R=V/I where R is the resistance in ohms (Ω), V is the voltage that we want to apply to the digital meter, and I is the current from the transducer.

- The CT5-010A provides an output of 1 mADC at 10 amperes AC through terminals 3 and 4. 1 mADC represents 10 amperes AC. Adjust the decimal point of the digital meter so that it displays 10.00 with 1 mADC through a 1000Ω load resistor.

- The VT-120A provides an output of 1 mADC at 150 volts AC applied to terminals 3 and 4. 1 mADC represents 150 volts. Adjust the decimal point of the digital meter so that it displays 150.0 with 1 mADC through a 1500Ω load resistor.

- The PC5-010A provides an output of 1 mADC at 1000 watts. 1 mADC represents 1000 watts. Adjust the decimal point on the digital meter so that it displays 1000 with 1 mADC through the 1000Ω resistor.

Now all three meters are scaled correctly and may be labeled amperes, volts, and watts. Note that the power does not equal volts times amperes. This is because the refrigerator has a power factor of 0.866 that is normal for older refrigerators. For the single-phase situation, power factor may be determined by dividing the power reading by the product of volts and amperes.

POWER, VOLTAGE, CURRENT, AND POWER FACTOR

In the example on page 13, we are monitoring only one phase for current, between two lines for voltage, and using a two-element watt transducer that measures two lines of current and two lines of voltage with respect to the third.
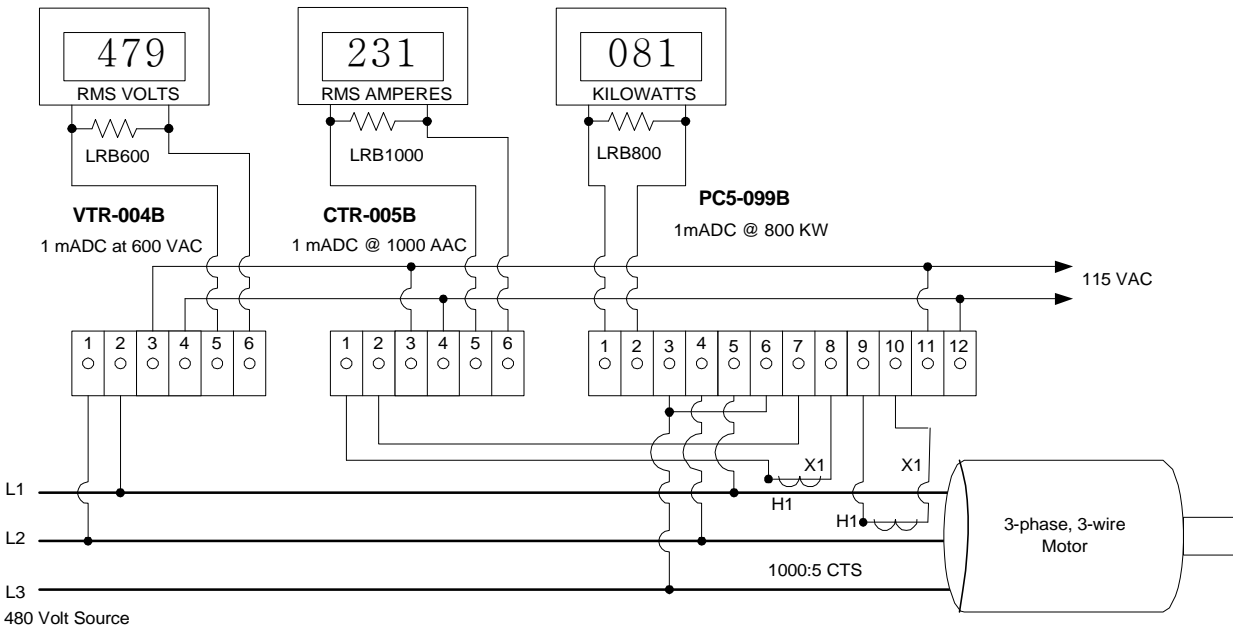
Determining Power Factor by Measuring Voltage, Current, and Power.

We are assuming a balanced condition to compute power factor given one current reading, one voltage reading, and total power.

Power Factor:

PF= watts ÷ (apparent power in VA). Apparent power for a three-phase, three-wire load may be calculated from the product of voltage, current, and the square root of 3 (1.732) or

$$PF = watts \div (V*I*1.732)$$

$$= 81,000 \div (479*231*1.732)$$

$$= 0.423$$

This is a low power factor and is very typical of some lightly loaded induction motors.

Where does the 1.732 come from? It is the square root of 3 rounded to three decimal places. The square root of three comes from the ratio of line to line voltage to line to neutral voltage in the three-phase system. Please refer to POWER MONITORING IN PART TWO of this brochure.

PITFALLS

Monitoring AC voltage and AC current is simple enough, but in monitoring power, one must follow the connection diagrams exactly.

- Watt transducers are polarity sensitive. They sense not only the power but also the direction in which it is flowing. Should a current transformer be installed backwards, the watt transducer will sense this as reverse power flow and provide an output reversed in polarity, a negative output.

- Watt transducers are also phase sensitive. If a current transformer is installed on the wrong phase line, the watt transducer will interpret this as a 120-degree phase angle shift and give the wrong result.

The most frequent complaint I receive on three-phase watt transducers is "I am not getting the correct output."

Conservatively stated, 90% of the time, the watt transducer is not correctly connected — a current transformer may be installed backwards or on the wrong line, voltage connections may be cross phased, or voltage connections may reference the wrong line. The other 9.5% of the time, the following gives the user trouble.

The electrical quantity – WATT – is a measure of the rate at which work is being done. If an electric motor is not doing any work or is doing very little work, it will not consume very much power in watts even though the electric current is relatively high. The power factor will be low and a watt transducer monitoring this motor will have a low output. This is to be expected! The output from a watt transducer reflects the rate at which the motor is doing work.

If you encounter incorrect readings from a watt transducer, double check your connections against the connection diagram on the transducer case or connection sheet. If you cannot solve the problem, give us a call.

COMMENTS

A watt transducer monitoring a three-phase, three-wire load must be a two-element watt transducer because the voltage, as measured and the current are out of phase by $\pm 30^\circ$ at unity power factor,

+30° on one leg and -30° on the other leg. Total power measured by the watt transducer is as follows:

$$P_{total} = [I_a * V_{ac} * Cos\ (\theta + 30°) + I_b * V_{bc} * Cos\ (\theta - 30°)]$$

Where:

- I_a is the current in leg A

- I_b is the current in leg B

- V_{ac} is the voltage between leg A and C

- V_{bc} is the voltage between leg B and C

- θ is the phase angle shift between the voltage and current — the power factor angle.

At a power factor of 0.867 one reading between two of the legs will be double that between the other two legs. The sum of the two is the correct total power.

At a power factor of 0.500 one reading between two of the legs will be greater than 0 and the other will be 0. The total of the two is the correct total power.

At a power factor of 0 the readings between the two sets of legs will be the same but opposite in sign. Again, the total of the two is the correct total power — zero! Please refer to Appendix D for more information on this topic.

This short paper does not even begin to cover all the situations one is apt to encounter in the real world. Some of the most common situations have been discussed. Please feel free to contact us at the factory. We are willing to assist you with your individual needs.

PART II

ELECTRIC POWER MONITORING

Ohio Semitronics, Inc. manufactures several series of watt (or power) transducers for monitoring AC, DC or variable frequency power. All watt transducers are solid state devices that use an analog electronic multiplier, Hall effect multiplier or electronic pulse-width, pulse-height-multiplying technique. All provide excellent accuracy and long life.

These include:

- PC4 series Hall effect for 400 hertz.
- PC5 series Hall effect for 50 or 60 hertz.
- PC8 series Hall effect for DC to 400 hertz
- P series Hall effect for variable frequency DC to 500 hertz.
- PC20 series electronic analog for 50 to 400 hertz.
- GW5 series pulse multiplication for 50 or 60 hertz
- AGW UL Listed, otherwise same as GW5.
- DW5 CSA Listed, DIN rail mount 50 or 60 hertz

Ohio Semitronics, Inc. can supply current and potential transformers for use with AC watt transducers. Please consult with your OSI representative or factory sales engineer for assistance with your application.


MEASURING ELECTRIC POWER

Power is defined as *p=iv* where *v* and *i* are the instantaneous values of the voltage and current. For constant DC, power is simply the product of the voltage and current. For AC it is not quite so simple.

For a resistive load on a 60 hertz single-phase system, the instantaneous power will have a waveform with a frequency of 120 hertz and varying from zero to $v_{max} * i_{max}$. (The peak voltage multiplied by the peak current.)

The following graph shows the power curve for the instantaneous product of voltage and current into a pure resistive load. The graph depicts one cycle of AC voltage and current applied to the load.
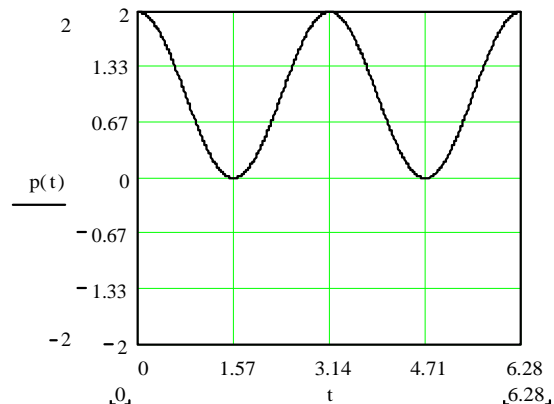
$$P := \left(\frac{1}{t2 - t1}\right) \cdot \int_{t1}^{t2} v(t) \cdot i(t) \, dt$$

Average power is defined as:

Or

$$P := \left(\frac{1}{t2 - t1}\right) \cdot \int_{t1}^{t2} v(t) \cdot i(t)\, dt$$

Or simply

$$P = I_{eff}\, V_{eff}$$

Where I_{eff} is the RMS value of the current and V_{eff} is the RMS value of the voltage. They are defined as:

$$Veff := \sqrt{\left(\frac{1}{T}\right) \cdot \int_0^T (v(t))^2\, dt}$$

$$Ieff := \sqrt{\left(\frac{1}{T}\right) \cdot \int_0^T (i(t))^2\, dt}$$

for a single frequency into a resistive load.

For a reactive load (Now that we have defined the root mean square – I_{eff} is the same as I_{rms} and V_{eff} is the same as V_{rms}.)

$$P = I_{rms}\, V_{rms}\, Cos(\theta)$$

where θ is the angle by which the current lags (inductive) or leads (capacitive) the voltage.

The graph in the next column shows the power curve for the instantaneous product of voltage and current applied to a single phase fully loaded motor. The motor has a power factor of 0.866 or a phase angle shift of 30°. This is normal for an older motor.
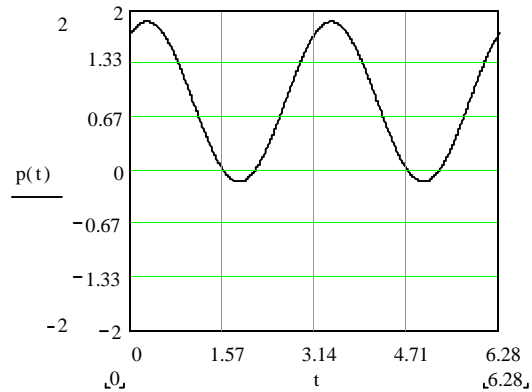
Note that with a phase angle shift of 30°, the curve begins to shift below the zero axes as shown in the above graph.

The following graph shows a single-phase load with a lagging power factor of 0.5 or 60°. Note that the power curve dips further below the zero axes. The portion of the power curve that dips below zero is regenerated power – power sent back into the utility lines.
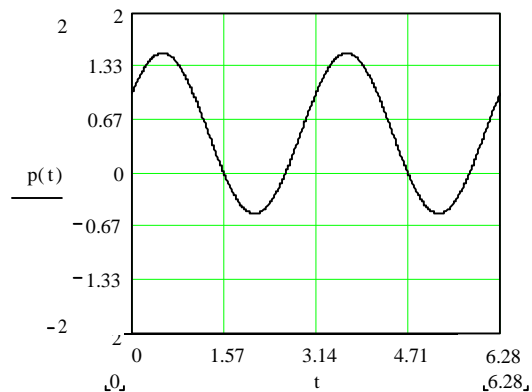
All standard, catalog listed watt transducers manufactured by Ohio Semitronics, Inc. provide an analog output that is proportional to the real average power as defined by the product of I_{rms} and V_{rms} and the cosine of the phase angle shift between the voltage and current, $P = V_{rms} I_{rms} COS\theta$.

All P and PC series watt transducers are capable of accurately measuring power when the current in non-sinusoidal, severely distorted, or chopped. (See appendix C)

Industrial loads such as motors have both resistive and reactive components. $V_{rms}I_{rms}COS\theta$ indicates that the actual power delivered to the load can be less than the maximum possible for the effective values of the voltage and current if θ were zero. The maximum is called the apparent power or VA. The ratio of real average power to apparent power is referred to as the power factor.

> **The ratio of real average power to apparent power is referred to as the power factor.**

PF = real average power divided by apparent power, PF = P ÷ VA.

In the sinusoidal case the power factor is simply COS θ where θ is the angle by which the current leads or lags the voltage. For this reason the angle θ is often referred to as the power factor angle.

A purely resistive load, one in which the voltage and current are in phase, will have a power factor of unity (1).

A purely reactive load, one in which the current and voltage are out of phase with each other by $\pm 90°$, will have a power factor of zero (0).
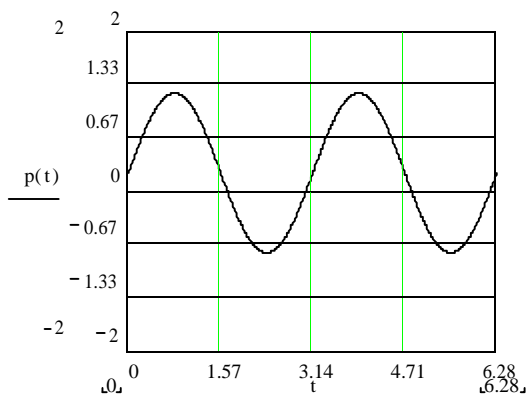
Above graph depicts a purely inductive load over one cycle. Note that equal portions of the curve are above and below the zero axis. The total net power delivered is thus zero.

The following graph depicts a purely capacitive load.
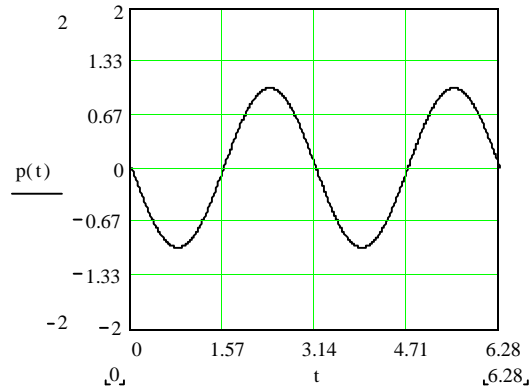
Between the two above extreme cases there are loads for which the power factor can range from zero to unity. The power factor of 0.5 indicates a load has an input impedance with a phase angle shift of either +60 or –60 degrees. The +60° describes a capacitive load and –60° describes an inductive load. The ambiguity in the nature of the load is resolved by referring to a leading or lagging power factor. The term leading or lagging power factor refers to the phase of the current with respect to the voltage. Therefore, and inductive load has a lagging power factor and a capacitive load has a leading power factor.

All watt transducers manufactured by Ohio Semitronics, Inc. have a power factor range of 0 lagging to unity to 0 leading.

Another important parameter is reactive power or volt-amperes-reactive – VARs. VARs refer to the component of apparent power that is purely reactive. For example using our two extremes, a pure resistive load has no reactive component while a pure reactive load has no real component.

The reactive power for a pure resistive load is zero, while for a pure reactive load it is $V_{rms}I_{rms}$. The three parameters 1) apparent power, 2) real power, and 3) reactive power are related as follows:

$$(VA)^2 = (P)^2 + (VAR)^2.$$

In the case of sine wave voltage and current, while real power is defined as $V_{rms}I_{rms}Cos\theta$ and apparent power as $V_{rms}I_{rms}$, the reactive power (Volt-Amperes-Reactive, VARs) is defined as $V_{rms}I_{rms}Sin\theta$.

HOW OSI WATT TRANSDUCERS WORK

THE AGW & GW5 SERIES OF WATT TRANSDUCERS

The GW5 series power transducers utilize stable, high-linearity multipliers to obtain the product of voltage and current required for true power measurement. The multiplier works on the pulse-height-width principle. Pulse height is proportional to the instantaneous current delivered to the load while pulse width is proportional to the instantaneous voltage. Time averaging of the pulse train output provides an output directly proportional to power transferred to the load for any phase angle combination.

The sampling frequency of the pulse-height, pulse-width multiplier is many times the power frequency in order to provide excellent results with sinusoidal wave forms or wave forms having harmonic content.

Use on SCR Controllers

Zero crossing or time proportioning SCR power controllers can be accurately monitored with the PC5 series transducers. Additional filtering is required to have a smooth output from the transducer. Please consult with the factory.

For phase angle fired SCR controllers use the PC5 or PC20 series analog watt transducer. These analog multipliers provide accurate measurement of the discontinuous waveforms.

PC AND P SERIES OF WATT TRANSDUCERS

All PC and P series watt transducers manufactured by Ohio Semitronics, Inc. utilize Hall effect or electronic analog four quadrant multipliers. The block diagram below shows how the PC and P series are structured.
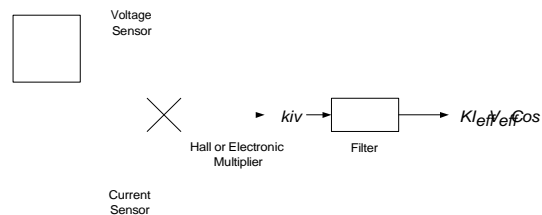

The Hall Effect

In 1879 E. H. Hall noticed that if a conducting material is placed in a magnetic field perpendicular to the current flow, a voltage perpendicular to both the initial current flow and the magnetic field is developed. This voltage is called the Hall voltage. It is directly proportional to both the strength of the magnetic field and the current. The Hall voltage results from the deflection of the moving charge carriers from their normal path by the magnetic field and its resulting transverse electric field.

Because the Hall voltage is proportional to both the magnetic field strength and the current, it may be used as an analog multiplier.

In a PC4 or PC5 watt transducer the following arrangement is used.
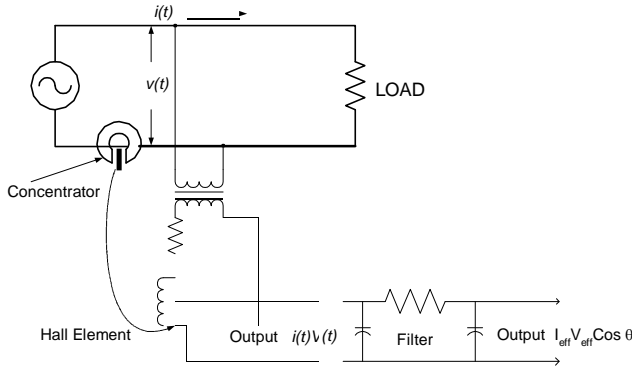
Notice that the Hall sensor has a current proportional to *v(t)* (the instantaneous voltage) flowing through it and a magnetic field through it that is proportional to *i(t)* (the instantaneous current). The output of the Hall sensor is proportional to both the instantaneous voltage and the instantaneous current — i(t)*v(t)* *k* where *k* is the Hall constant.

In the P and PC8 series of watt transducers the principle is the same, except a differential isolation amplifier replaces the potential transformer.

The PC8 series arrangement is shown below.
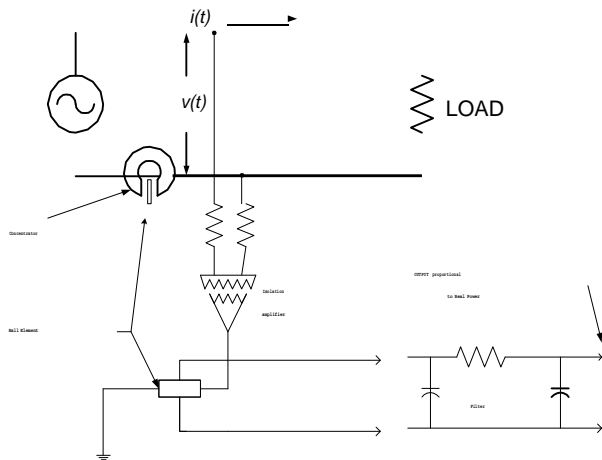
Again the output is proportional to *i(t)*v(t)*. This time, because the potential transformer has been eliminated, these transducers are frequency independent at least with in the limits of the isolation amplifier, core material in the current sensor, and the Hall sensor. The P has a flat response from DC through 500 hertz and the PC8

has flat frequency response from DC through 400 hertz. In the P series the isolator follows the output circuit.

Looking at Power

The PC5 and PC4 series watt transducers may be special ordered from Ohio Semitronics, Inc. with an unfiltered, instantaneous output. This instantaneous output can yield some useful information if viewed on an oscilloscope.

Let the current through the Hall sensor be Ic which is proportional the voltage applied to the load,

$$I_c \approx V * Sin(\omega t),$$

And the magnetic field proportional to the current drawn by the load,

$$B \approx I * Sin(\omega t\text{-}\theta),$$

Where θ is the phase angle shift between the voltage and current.

The output of the Hall sensor then can be represented as:

$$V_H \approx [I\ Sin(\omega t\text{-}\theta)] * [V * Sin(\omega t)]$$

Or

$$V_H \approx \tfrac{1}{2} * I * V * [Cos(\theta)\text{-}Cos(2\omega t + \theta)]$$

Note that the above consists of two terms:

1) $I * V * Cos\ (\theta)$ a DC term and,
2) $I * V * Cos\ (2\omega t + \theta)$ an AC term.

The DC term, $I * V * Cos\ (\theta)$, is the familiar power formula for AC (sine wave) power and is directly proportional to real power in watts.

The AC term, $I * V * Cos\ (2\omega t + \theta)$, is twice the input frequency and is directly proportional to the apparent power.

One can determine the relationship of real power, apparent power, and power factor using a DC coupled oscilloscope and a single phase power transducer that is monitoring a single phase load.

The Y input of the oscilloscope should be connected to the watt transducer output (instantaneous) terminals. A DC coupled scope is required because the transducer output will have both AC and DC components.

Adjust the oscilloscope for a suitable horizontal sweep rate.

With power flowing to the load, a waveform similar to the following should be observed.

The trace is a sinusoidal waveform at twice the line frequency to the load. If the line frequency is 60 hertz, then the power waveform will have a frequency of 120 hertz. This comes from the term

$$I * V * Cos(2\omega t + \theta).$$

The above example illustrates a purely resistive load. Should the load have a reactive component, then the trace will dip below the zero axis.

To determine power factor use the following procedure:

1. Adjust the oscilloscope gain to obtain a peak-to-peak waveform excursion of two divisions. Use the oscilloscope in the **AC mode** for this.
2. Check oscilloscope zero and adjust as necessary to provide zero indication of zero input.
3. With oscilloscope set for DC input observe the waveform.
4. Power Factor can be determined directly by the following example.
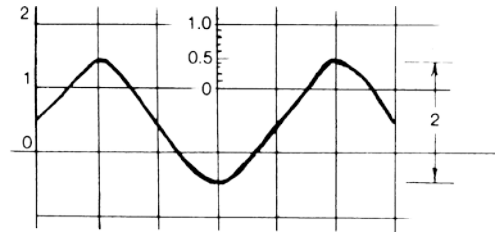
5. The Power Factor can be read directly as the peak value of the sine wave on a scale of 0 to 1 between the 1st and 2nd divisions above the zero on the oscilloscope screen.

DC POWER

Monitoring DC power used to be easy when resistive type controllers were used. A select few of you may remember the banks of resistor grids that trolley cars held in a cage beneath the car. The motorman controlled the power to the motor by adding or subtracting resistor grids in series with the motor.

In our energy conscience world today, the use of resistor grids is considered wasteful because the resistor grids and the motor are consuming power. Power consumed by the resistor grids is thrown away as heat.

Today DC motors often use electronic choppers or pulse width modulated controllers that vary the effective voltage applied to the load. Since a motor represents a load which has both resistive and reactive components, power is no longer the simple product of voltage and current.

If a voltage pulse is applied to the motor, then the current will have the form of:

$$I = (V/R) * (1 - e^{-Rt/L})$$

Where V is the applied voltage,
R is the resistance in the circuit,
L is the inductance, and

t is the time.
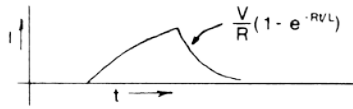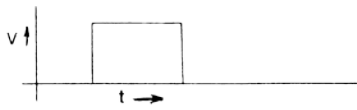
Power consumed is:

$$P = V * [(V/R) * (1 - e^{-Rt/L})]$$

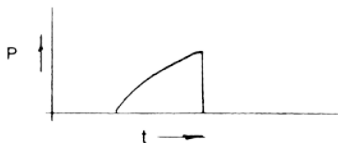With waveforms such as these applied to the motor at frequencies of 20 to 400 hertz and with the resultant harmonics, the OSI PC8 or P series watt transducers will provide accurate measurement of real average power delivered to the load. With Pulse DC input the output of the Hall multiplier will again consist of a DC term and an AC term. The DC term represents real power.

VARIABLE FREQUENCY POWER

DC motors have traditionally been used where variable speed applications exist. Over the past three decades the motor and drive industry has moved toward variable speed AC drives. Variable speed is achieved by varying the frequency delivered to an induction motor. The rotational speed of an induction motor is dependent on the frequency of the applied voltage. Drive manufacturers such as Allen-Bradley, Siemens,

Reliance Electric, Magnetek, and others build motor controllers – drives – in which the fixed frequency voltage is rectified and the resultant DC voltage is then converted to three-phase AC the frequency of which can be varied from a low to a higher value. A typical frequency range for a variable frequency drive might be 6 to 66 hertz.

Standard current transformers cannot handle frequencies as low as 6 hertz. Hall effect current transducers have a flat frequency range of DC through 5000 hertz.

The OSI P series watt transducers are specifically designed for variable frequency power. These transducers provide a useful frequency range of DC through 500 hertz and have flat frequency response to 5000 hertz.

AC POWER (Single Phase)

Our homes and small offices are wired for a single-phase, three-wire system often referred to as the Edison System. This is shown below.
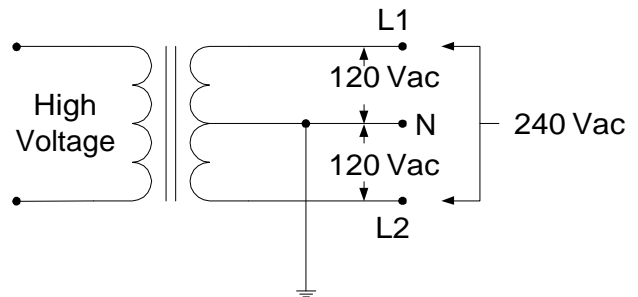

Loads may be connected as show below and on page 5.
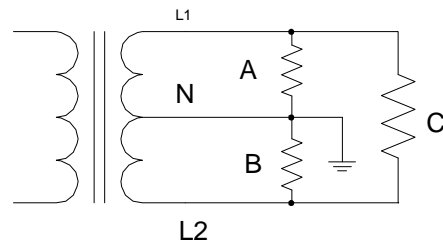
Loads shown as A and B are typically small appliances and lighting fixtures while loads shown as C are typically large appliances or heating devices such as electric clothes dryers and electric stoves.

Power monitoring on an Edison System can be achieved by using a two-element power transducer connected as follows:

Two Element Watt Transducer
**2 multipliers in the same case**
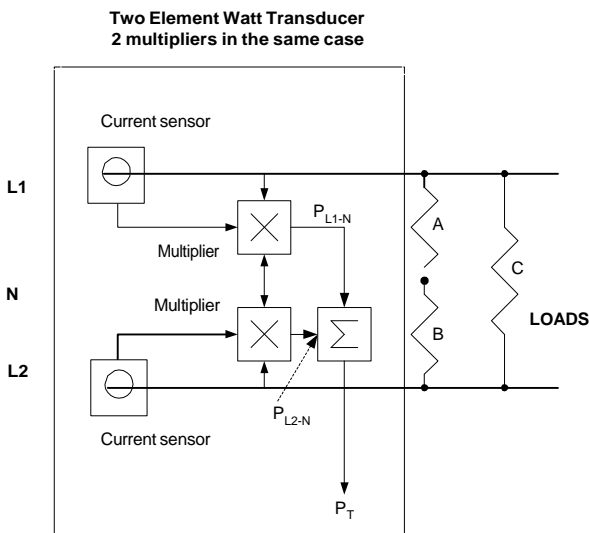
The total power used in the system will be the simple sum determined by the two elements. Each element is a multiplier. A two-element watt transducer has two multipliers.

A two-element watt transducer is required for monitoring the combined loads in a home or small office, which is wired for 240 and 120 volts single phase with a three-wire hookup. This two-element watt transducer is connected from each phase line to the neutral. The transducer should be rated for 120 volts AC.

Polyphase

Almost the entire output of the electric power industry in the United States is generated and distributed as polyphase power at 60-hertz frequency.
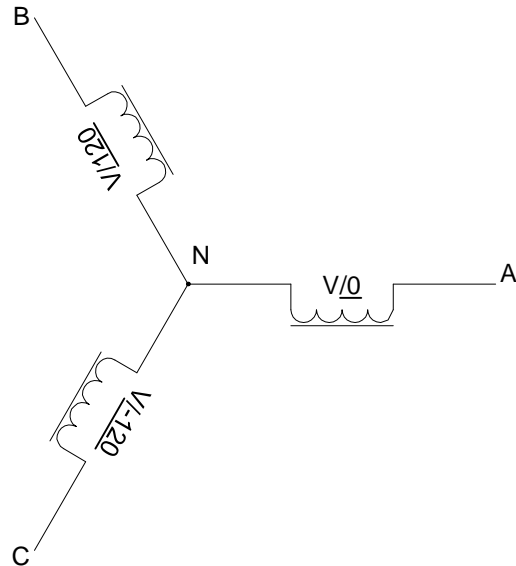
In a three phase system as represented above, the three voltages V_{AN}, V_{BN}, and V_{CN} are mutually out of phase by 120°. A balanced load will draw equally from the three phases; however, when one of the voltages is instantaneously zero, the phase relationship shows that the other two must be at half amplitude. At no time does the instantaneous power drawn by the load reach zero. In fact the total instantaneous power drawn by the balanced load is constant! This is a big advantage for rotating machinery because it maintains a more constant torque than if a single-phase motor were used. Also, there are economical reasons for transmission of electrical power by a three-phase system.

> **. . . the total instantaneous power drawn by the balanced three-phase load is constant!**

Power supplied by the generating facility is connected as shown above. This is referred to a "Y", "Wye," or three-phase, four-wire connected system. To determine the total power each of the three branches must be monitored. The total power delivered by the source the load will be the simple sum of the readings of the wattmeters on each branch.
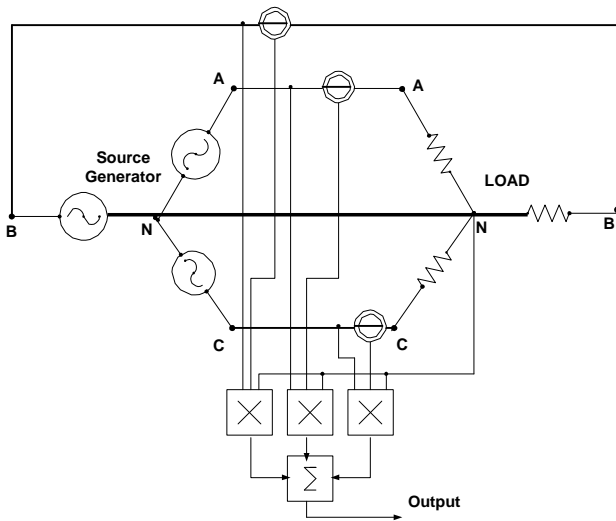
OSI watt transducers for monitoring a wye-connected load have three individual multipliers contained within the case. The output of the package is proportional to the total power consumed by the load. A watt transducer that contains three separate multipliers is referred to as a three-element watt transducer.

As you recall a balanced three-phase load will draw constant power, therefore, the output from a three-phase OSI watt transducer will be constant assuming constant loading on the motor being monitored. The instantaneous output signal from an unfiltered watt transducer will immediately reflect any change in loading without the familiar 120-hertz power ripple.

THE THREE-PHASE, THREE-WIRE CONNECTION

Many loads including most three-phase electric motors are connected to a three-phase source from line to line with no connection to the neutral.
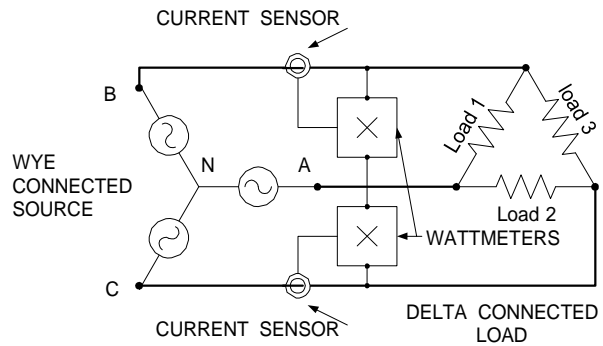
The above could be monitored accurately using a three element watt transducer wired in a wye configuration. Interestingly, if the neutral terminal of the watt transducer is not connected, the transducer reads correctly. Further, if on a delta connected load as shown above, the neutral connection is tied to one of the three phase lines, the watt transducer will still read correctly regardless of the imbalance in the load. This is a direct result of Kirchoff's Laws of Current and Voltage.

KIRCHOFF'S LAWS

Current: The algebraic sum of the current in all lines of a circuit must at any given instant be zero.

Voltage: The algebraic sum of the voltages among the nodes of a circuit must at any given instant be zero.

This information may be applied to a three-wire circuit. Since the algebraic sum of the three current must be zero, the instantaneous sum of two of the currents gives the negative value of the third. Likewise with the voltage, the algebraic sum of two of the voltages gives the negative value of the third. In a three-phase, three-wire circuit a two-element watt transducer is required. In a three-phase, four-wire circuit a three-element watt transducer is required.

BLONDEL'S THEOREM

For any (n) wire system, (n-1) wattmeters or elements are required to measure total power.

An older transformer arrangement that frequently causes confusion is the grounded delta. The grounded delta connection provides 240 volts three-phase, three-wire for motor loads and 120 volts single-phase for office lighting and other light loads. Because this is a 4-wire system, a three-element watt transducer is required.
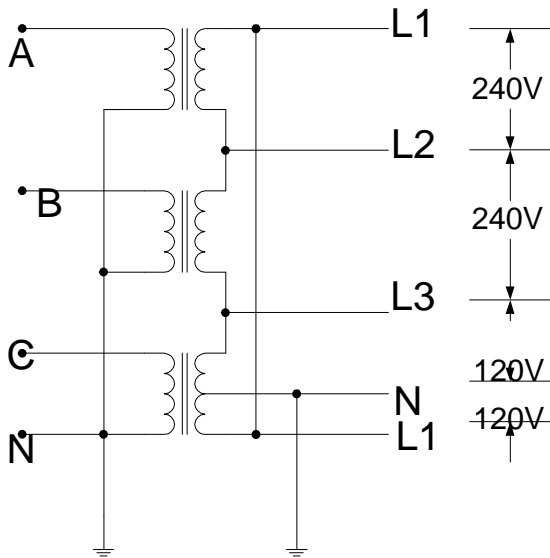
VOLTAGE RELATIONSHIPS IN A THREE-PHASE SYSTEM

The polyphase watt transducers manufactured by Ohio Semitronics, Inc. are rated for voltage in two ways:

- Three-phase, three-wire **two-element watt transducers** are rated for **line to line voltage.**
- Three-phase, four-wire **three-element watt transducers** are rated for **line to neutral voltage.**

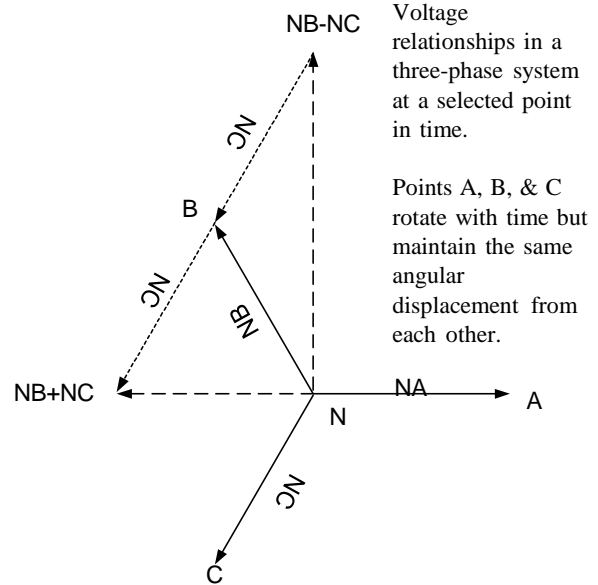The vector diagram below illustrates the voltage relationships in the three-phase system.

Voltage relationships in a three-phase system at a selected point in time.

Points A, B, & C rotate with time but maintain the same angular displacement from each other.

As one can see, the voltage measured from C to B is the vector difference NB-NC and has a magnitude greater than the line to neutral voltage by a factor of $\sqrt{3}$ (the square root of 3 or 1.732…) and a direction of 30° behind NB. This, if the line to neutral voltage is 120 volts, then the line to line voltage is $\sqrt{3} * 120$ or about 208 volts. Likewise if the line to line voltage is 480 volts, then the line to neutral voltage is $480 \div \sqrt{3}$ or about 277 volts.

After looking at the vector diagram above, one might realize that some tricks could be performed. Since the voltage difference between two phase lines has an angular displacement of 90° from the third voltage with respect to the neutral, that voltage difference can be used to determine the reactive power of a balanced system. Recall that reactive power is defined as

$$I * V * Sin(\theta)$$

while real power is defined as

$$I * V * Cos(\theta).$$

If one applies the voltage NB-NC, that which is measured from phase line C to phase line B, and

the current in phase line A to a standard watt transducer, the output will be proportional to

$$\sqrt{3} * I * V * Cos(\theta + 90°).$$

But, $Cos(\theta + 90°)$ is $-Sin(\theta)$

So the output of the watt transducer will be proportional to volt-amperes-reactive, VARs, rather than to real power. This is the principle by which the OSI VAR5 series of VAR transducers operate.
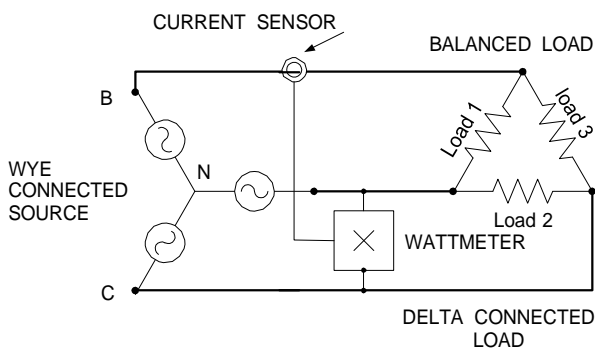
SINGLE-PHASE WATT TRANSDUCER
CONNECTED TO MEASURE VARS

Another trick one may use to save money for monitoring a high voltage three-phase, three-wire load is the 1-½ element watt transducer.

Potential transformers are often more expensive than the watt transducer. To save the cost of a potential transformer, one can connect a single potential transformer between two phase lines and measure the current in each of those same two phase lines. The potential difference and the current difference between those two lines have the same angular relationship at unity power factor. One can accurately measure the power for any power factor so long as the load is balanced.

ENERGY MONITORING

Electrical energy is defined as the time integral of electrical power or for a constant load – watts multiplied by time. The most common units of electric energy are the kilowatt-hour, the watt-hour, and the watt-second or Joule.

Power Curve
Energy is the Area under the Curve.
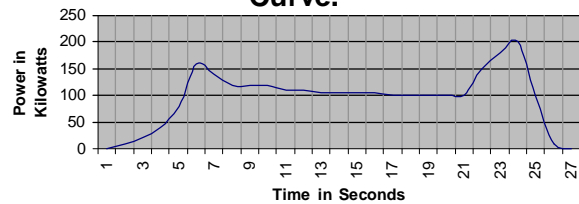
$$Energy := \int_{t1}^{t2} p(t)\, dt$$

Or

Energy = the area under the power curve.

One can approximate the energy under the above curve by counting the number of rectangles. Each rectangle represents one second of time on the X-axis and has a height of 50 kilowatts. Therefore each rectangle represents 1 Sec X 50 kW = 50 kilowatt seconds or 50 kilo-Joules of energy. There are 43 whole rectangles and enough fractional rectangles to make approximately 45.5. The total energy then is 45.5 X 50 kilo-Joules or 2275 kilo-Joules of energy.

Ohio Semitronics, Inc. uses another technique to very closely approximate total energy. OSI utilizes a precision integrator. This electronic, solid state integrator is a voltage to frequency converter (VFC) that produces a pulse train at a frequency that is proportional to the measured power. Each pulse represents some very small unit of energy.

The calibration is done at a high frequency. This frequency is then divided down to a slower rate such that each pulse represents some multiple of 10 watt-hours. The output of the precision integrator may be connected to a counter and calibrated so that the counter registers directly in kilowatt-hours, or even Joules (watt-seconds).

Functionally an electronic watt-hour meter or Joulemeter is structured as shown below.
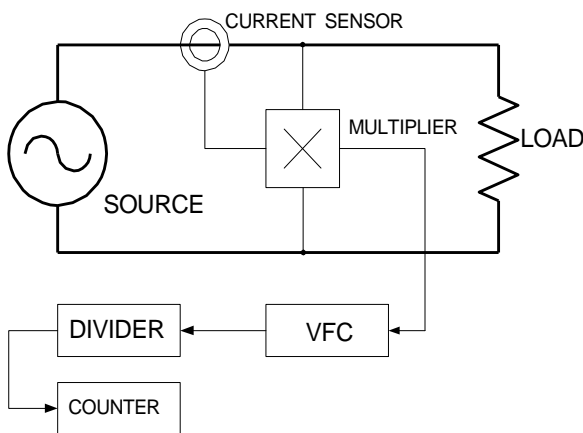
The counter accumulates watt-hours

Solid state watt-hour meters for AC are the OSI standard models WH30 and WH50 series for AC and the WH70 series for DC. All three are supplied with digital wattmeters and digital counters for recording watt-hours and supply an analog output proportional to power and a pulse output for watt-hours.

As of 2004 the WH30, WH50, and WH70 are no longer listed in the OSI catalog. These may be special ordered from Ohio Semitronics, Inc. Please contact the factory.

Many OSI customers order watt-hour meters with a "no load offset" control. This is used to tare out the power consumed by the unloaded device or motor. Then, when the device or motor is loaded, i.e. doing useful work, only the power doing useful work is recorded and likewise only the energy put into the workload is accumulated.

In the example that follows if the power required running the unloaded motor is cancelled out or "zeroed" and the clutch is then engaged, only the power and energy delivered by the motor are registered.
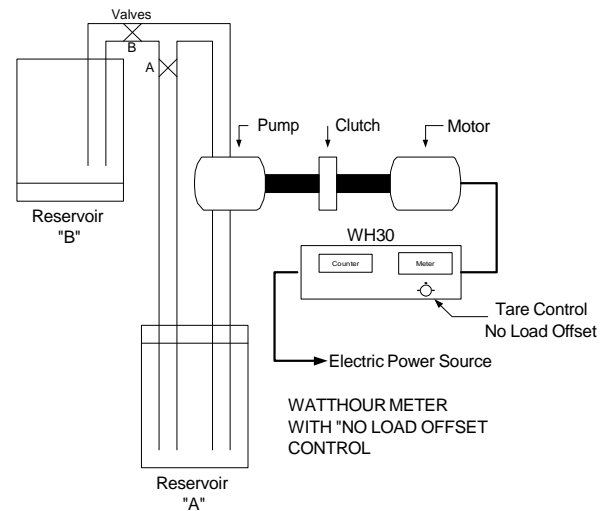
One can take this a step further. With valve B closed and valve A open, one can zero out the power used to move the fluid without lifting it to a higher level. Open valve B and close valve A. Now measure the power required to pump the fluid from reservoir A to reservoir B. In this manner, one measures the energy required to transfer the fluid to a higher level.

This principle if frequently used in industry to monitor the quantity of energy put into a process. Examples include mixing operations, grinding processes, heat transfer efficiency, welding processes, heat treating, and more.

TERMS AND CONVENTIONS USED

Terms

Active Power. (Real Power) The time average of the instantaneous power over one period of the wave.

Apparent Power. The product of RMS Voltage and RMS Current, expressed in Volt-Amperes (VA).

Averaging. Method of measurement based on the average absolute value of the input signal.

Burden. The load imposed by a device on an input circuit, expressed in Ohms or VA.

Cal. Refers to the calibration adjustment of an OSI product.

Compliance (Voltage). Maximum output voltage that a transducer current output can maintain within the specified load resistance range.

Current Transformer. Transformer that utilizes the line conductor being measured as a primary and develops a secondary current, or output, which is proportional to the primary current. The measurement range is expressed as the ratio of full-scale primary current to full-scale secondary current. Sometimes referred to as instrument transformers or "doughnuts."

DC Insertion Loss. Power loss due to resistance of measuring device, zero in the case of Hall effect sensors.

Delta. Three-phase three-wire power system configuration.

Direct Measurement. Measurement of a waveform that provides an output that is proportional to both amplitude and direction and has the same frequency as the input waveform.

Edison System. Single-phase three-wire system, typical household configuration. This requires a two element Watt transducer for accurate measurement of power.

Elements. The number of single-phase watt multipliers required to accurately monitor a polyphase system. Example: A two element watt transducer is required to monitor a three-phase three-wire system.

External Power. Requires connection to external power source.

External Sensor. Unit is supplied and calibrated with current transformer(s) to allow measurement of specified current range.

Full-Scale Counts Per Hour. The total number of dry contact closures or pulses that will be generated by an OSI Watt-hour transducer in one hour with power input at full-scale.

Grounded Delta. Three-phase three-wire system with a grounded center tap. Typically used for 120V circuits. Requires a three-element watt transducer for accurate power measurement.

Hall Effect. A conducting material placed in a magnetic field perpendicular to the direction of current flow develops a voltage across that material in a direction perpendicular to both the initial current direction and the magnetic field. This voltage is called the Hall voltage, after E. H. Hall who first observed the effect in 1879. The Hall voltage arises from the deflection of the moving charge carriers from their normal path by the applied magnetic flux and its resulting transverse electric field.

Integral Sensor. Unit can be directly connected to a current input without using current transformers. Do not exceed full-scale current rating.

Loop-Power(ed). Method of supplying power to some OSI products via externally powered 4-20mA (15-40Vdc) control loop.

Output Loading. Specification stating the total resistance of circuits and devices connected externally to an OSI product.

Potential Transformer. Transformer in which the primary winding is connected in shunt with a power supply circuit. Voltage measurement is expressed as the ratio of full-scale primary voltage to full-scale secondary voltage. Primarily used to "step-down" high voltages to allow input into a transducer.

Phase Angle. The angular displacement of a sinusoidal voltage waveform to a sinusoidal current waveform, expressed in degrees.

Power Factor. The ratio of total watts (active power) to the total RMS Volt-Amperes (apparent power). In the case of a sine wave the power factor can be calculated as the cosine of the phase angle.

Quiescent Current. Power supply current with zero signal input.

RMS (Root-Mean-Square). The square root of the average of the square of a function taken through one period, will be equal to 0.707 of peak for a sine wave input.

RMS Measurement. Measurement of a waveform which provides a dc output proportional to the RMS value of the input waveform.

Self-Powered. Power for an OSI product is supplied by the circuit being measured, no external power is required.

Split-Core. Hall effect current sensor or current transformer which can be taken apart for installation or removal.

VAR (Volt-Amperes Reactive). Unit of reactive power.

VA (Volt-Amperes). Unit of apparent power.

Watt. Unit of active power.

Wye. Three-phase four-wire power system configuration.

Zero. Refers to zero adjustment of an OSI product.

Conventions and Symbols

Lower case characters in Italics indicate instantaneous or time varying quantities. *i* represents instantaneous current, *v* represents instantaneous voltage, *p* represents instantaneous power. The lower case *t* in parentheses is used to show time varying quantities for example *i(t)* or *v(t)* for time varying current or voltage.

Capital letters used as symbols designate DC or effective values.

V_{AN}	Effective voltage from phase A to Neutral
I_B	Effective current on phase B.
V_{l-l}	Effective line to line (phase to phase) voltage
V_H	Hall voltage. The voltage output from a Hall effect device.
L	The inductance of a circuit.
R	The resistance of a circuit.

$\sqrt{}$	Square root symbol.
θ	Greek letter theta use to indicate angular displacement between voltage and current in an electric circuit.
$\approx$	Used in this paper to indicate proportionality.
Ω	Greek letter Omega used to indicate the electrical quantity of resistance in ohms.
$\circ$	Symbol for degrees.
$\int$	Integral symbol.
ω	Time varying angular quantity.
$\angle 30°$	Fixed angular relationship (30 degrees in this example).
t	Time
e	Base of natural logarithm – 2.71828…
$*$	Used in this paper to designate multiplication.
$\div$	Division symbol.
/	Also used to indicate division.
Cos	Cosine function
Sin	Sine function
max	The maximum value of a time varying quantity.
min	The minimum value of a time varying quantity.
eff	The effective value of a quantity. The same as the rms value of voltage or current.

Appendixes

Appendix A: True RMS Measuring versus Average Absolute Measuring Current and Voltage Transducers Where Harmonic Distortion exists.

A discussion with graphs and calculations showing why one should use true RMS measuring transducers and meters when ever there is harmonic distortion.

Appendix B: True RMS Measuring VS Average Absolute Measuring Current and Voltage Transducers where a phase angle fired SCR controller is being used.

A discussion with graphs and calculations showing why one should use true RMS measuring transducers and meters when measuring voltage and current controlled by a phase angle fired SCR.

Appendix C: Results of Measuring Power Controlled by a Phase Angle Fired SCR Controller.

Test results from measuring a load controlled by a phase angle fired SCR. Test uses an older PC5 watt transducer that had been removed from service.

Appendix D: Use of a Single Element Wattmeter or Transducer on a Balanced Three-Phase, Three-Wire Load Will Not Work. Here's Why.

Appendix E: The Two Wattmeter Method.

A discussion on why the two-wattmeter method works on a three-phase, three-wire sourced load regardless of how the load is internally connected and regardless of imbalance.

Appendix F: Monitoring Variable Frequency Drives (VFD).

Unexpected reading can occur when measuring voltage and current delivered by a VFD to a motor load. This paper discussed why these unexpected readings occur.

Appendix G: Waveforms from a Six Pulse DC Drive using Phase Angle Fired SCRs.

This paper discussed the special considerations and special features that current and voltage measuring transducers must have to accurately measure waveforms produced by these controllers. This paper uses graphics to illustrate what is happening with the current and voltage waveforms.

Appendix H: Measuring Power Regulated by Zero Crossing SCR Controllers.

If these appendixes are not attached, please contact Ohio Semitronics, Inc. and request the appendixes that you require.

Summary of Transducers Series Manufactured by or Sold by Ohio Semitronics, Inc.

Current
(non-hall effect)

CTY & CTX split-core current transformers. These are available with a voltage output. Many customers use these as AC current transducers with an instantaneous output.

CT7 Instantaneous measuring current transducers. Output is directly proportional to the input in magnitude and time. DC to 500 hertz.

ACT, 3ACT, CT5, 3CT5, MCT5, CTC, CTD, SCT, DCT   These are all average absolute measuring current transducers that are well suited for monitoring motor or other loads, which have nice, clean sine wave current.

ACTR, CTR, 3CTR, CTRS, DCTR, CT8, VT8 shunt isolator - True RMS measuring current transducers.

Current
(hall effect)

CTL For AC or DC applications there are models from 35-ampere models to 40,000-ampere models. The CTL series is used with (and typically calibrated with) a signal conditioner. Standard catalogue listed models are UL Listed.

CTG For DC applications. The CTG series require a ±15 volt supply for operation. These have built in signal conditioning. Standard catalogue models are UL Listed and range from 100-ampere models to 5000-ampere models.

CTH For DC applications. The CTH series may be operated from a 24-volt DC or AC supply. Options include operation from ±15-volt DC supplies or other voltages. Models range from 25-ampere models to 1500-ampere models.

ISC are hall effect current transducers built and certified to be intrinsically safe. UL and CUL certified and meet ATEX Directive 94/9/EC. These are for use in hazardous locations. Models available from 100-ampere models to 2500-ampere models.

CTF and CTFB closed loop (feed-back) type hall effect current transducers. These may be used in AC or DC circuits. The output is directly proportional to

the input in magnitude and time. Models from 100-ampere models to 500-ampere models are available.

CTU For DC applications. Not all of these are listed in our catalogue. The series consists of printed circuit board mount transducers and special purpose open loop hall effect current transducers. Models range from a 25-ampere model and up. Please consult with our factory.

Voltage

AVT, MVT, DVT, 3AVT, 3VT, DVT These are all average absolute measuring voltage transducers that are well suited for monitoring clean sine wave voltage.

AVTR, VTR, 3VTR, DVTR, VT8 These are all true RMS measuring voltage transducers.

VT7 Instantaneous voltage transducer for AC or DC applications. The output is directly proportional to the input in magnitude and time. Models range from 0.05-volt to 1000-volt models.

VTU DC voltage transducers are unidirectional only. Output is proportional to the DC voltage input. Models range from 0.05-volt input to 1000-volt input models.

VTH DC voltage transducer providing 10 kV isolation. These are unidirectional. Models are available from 0.05-volt to 4000-volt models.

Watt (Power) and Watt-hour transducers
(AC only models are available with 1, 2, 2.5, or 3 elements)

PC5 & PC4 The PC5 and PC4 series are our oldest, most popular, and most versatile transducer series for accurately measuring active (real) power in a wide variety of situations. Accuracy is better than ±0.5%. PC5 for 50 or 60 hertz. PC4 for 400 hertz.

AGW, GW5, DW5 series provide excellent accuracy for most situations. 50 or 60 hertz.

AC Watt transducers for variable Frequency

P The P series is designed specifically for monitoring the output from variable frequency drives (VFD). The

frequency range of these transducers is DC or 5 to 500 hertz. These are available in 1, 2 or 3 element models and are supplied with CTL current transducers.

PC8 The PC8 series was conceived for measuring DC power but they work from DC to 400 hertz. These are available in single element models only and are supplied with a CTL current transducer.

MT The MT series was conceived for measuring DC power using a shunt and direct voltage input. However, OSI does provide versions of these for variable or fixed frequency on request.

DC Watt Transducers. Use PC8 or MT listed above.

AC Watt and Watt-hour Transducers

W The W series watt and watt-hour series provide a pulse or contact closure output for watt-hours and an analog output proportional to active power. The W series is based on the PC5 and PC4 watt transducers with an integrator circuit added for energy. Use W4 for 400 hertz.

AGH and GH series watt and watt-hour transducers are based on the GW5 and AGW watt transducers with an integrator circuit added for energy.

AC Watt-hour Transducers —Models that only have a pulse output for watt-hours or a analog output is optional

WL40R, WL42R, WL45R are all obsolete models that OSI no longer supplies. They have been replaced with the WL50 and WL55 series.

WL50 and WL55 watt hour transducers. These series provide a pulse output for watt-hours. They are available with an optional analog output.

SWH This series measures bi-directional energy on single phase, 2-wire loads only. These provide a solid-state contact closure for watt-hours. Please consult factory.

DC Watt Hour Transducers

OSI does not manufacture a DC watt-hour transducer. Use model series VFC integrator with either a PC8 or MT to measure DC watt-hours.

Frequency Transducers

FT, AFT, DFT narrow range frequency transducers. Models available for 50, 60, or 400 hertz applications.

AFT, DFTA, FTA wide range frequency transducers. Models available from DC to 1000 hertz.

DFD differential input frequency transducers are available for 50, 60, or 400 hertz.

Power Factor or Phase Angle Transducers

PF5 series phase angle transducers are available for 50, 60, or 400 hertz. The output is proportional to the phase angle displacement between voltage and current.

(Multifunction transducers that measure power factor. See multifunction for more information.)

PC20, PTB, DLM, DMT, DWV, Custom units.

VAR or Volt Amperes Reactive

VAR5 These are cross-phase connected PC5 watt transducers that supply an analog output proportional to reactive power. These are available in three-phase models only. VAR5 transducers are not frequency sensitive and can handle distorted current.

GV5 These are based on the GW5 watt transducers. This series utilizes a phase shift circuit to obtain $IE\cos(\theta-90°) = IE\sin\theta$. Available for 50 or 60 hertz. Fixed frequency only.

GWV This series is a combination watt and VAR transducer. See multifunction transducers for more information.

DWV This series is listed as a combination watt and VAR transducer. Please see multifunction transducers for complete information.

VAR Hour Transducer

VGH This series is based on the GV5 with an integrator circuit added. It provides both an analog output for reactive power and a pulse output for VAR hours. Fixed frequency only. Available for 50 or 60 hertz.

Also see Multifunction Transducers.

Multifunction Transducer. Transducers that measure two or more parameters. Does not include watt and watt-hour transducers already described.

PTB This series is a board level multifunction transducer that measures true RMS voltage and current on each phase and total power. Optionally it can measure apparent power (VA) and power factor and/or watt-hours. This board has been popular with system integrators.

PC20 this series measures active power, apparent power and power factor. It is the predecessor of the PTB board. Accurate from 50 through 400 hertz.

DWV is listed as a combination watt and VAR transducer in our catalog. However it is easily programmed at our factory to measure up to 3 parameters. These parameters can be almost any commonly measured electrical parameter — power, VA, VAR, PF, I, E, and more. Please contact OSI for information.

DMT Several model series of the DMT are available. These can provide up to 4 analog outputs, 4 pulse outputs, and/or RS-485, and more. The DMTs can measure up to 48 parameters. Please contact us.

DSP Transducers are based on DSP technology. Standard catalog models provide an RS-422 interface only. These measure true RMS current and voltage each phase, active power each phase, total active power, and frequency. Custom versions are available. An eight channel analog module is available for the DSP. Software is available free with DSP.

DLM This is a panel mount, multifunction LCD meter with an RS-422/RS-485 interface. It can measure true RMS current and voltage each phase, active power each phase, total active power, frequency, reactive power, apparent power, power factor, watt-hours, VAR hours, VA hours, and demand over a fixed 15 minute interval. User programmable. Software available free with meter.

A210 multifunction panel mount LED meter is user programmable to measure most common electrical parameters. Module available for RS-232 and data storage. Consult factory.

A2000 multifunction panel mount LED meter is user programmable to measure most common electrical

parameters. Has RS-232 for programming and reading the meter. Software may be downloaded free off the internet. Consult factory for more information.

Ohio Semitronics, Inc. does manufacture a "do it all" power display meter, the PDM. This instrument, which is based on DSP technology, can support a local LED display and/or up to 16 remote LED displays. It has an RS-232 and/or an RS-485 interface and can be supplied with an analog module to provide analog output signals. This module will work properly on AC, DC, or variable frequency from VFD's. Please contact us as this system provides an economical means of measuring multiple parameters including temperature.

UL US and CUL Listed Model Series
UL and CUL Listings apply only to models listed in our Catalog #404. Modified versions may not be UL listed. Please check with our factory.

3ACT, 3AVT, ACT, ACTR, AFT, AGH, AGW, AVT, AVTR, CTC, CTD, CTG, CTH, CTI, CTL MCT5, MVT, SCT

CSA Approved Model Series
Approved models apply only to models listed in Catalog #404.

A210, A2000, DCT, DCTR, DFD, DFTA, DMT, DVT, DVTR, DW5, DWV.

Email:
support@ohiosemitronics.com
Ohio Semitronics, Inc.
4242 Reynolds Drive
Hilliard, Ohio USA 43026
Tel: 614-777-1005
           800-537-6732
www.ohiosemitronics.com