Electrical Transducers by Mike Hopkins Msc

INTRODUCTION TO ANALOGUE TRANSDUCERS

A power system requires some form of instrumentation to monitor and control its operation. In the past this function has been performed by electro-mechanical devices. With these devices their use was limited by being confined to close to the point of measurement. Replacing these mechanical devices with their electronic equivalents has allowed the monitoring system to become more versatile. A modern system usually involves the transmission of information from the point of measurement to other points where this data is processed, recorded and used to control the system parameters. The conversion and transmission of physical parameters on the system requires the use of transducers at the points of measurement. These transducers act as the interface between the power system and the measurement system.Electrical transducers are specifically transducers for converting the raw voltage and currents in a power system into useful and meaningful electrical signals which can be used in and transmitted about the measurement system. The inputs to these devices are usually currents and voltages from instrument transformers such as current transformers (CTs) and voltage transformers (VTs) whilst the outputs are standardised dc currents or digital signals.

The requirements of electrical transducer users are very similar and individual manufacturers of transducers produce a range of product which is fairly standard. Although the transducers referred to in these notes are specifically those manufactured by Carrel and Carrel Ltd much of the information given can be applied to transducers in general.

TYPES OF ELECTRICAL TRANSDUCER

Traditionally most electrical transducers are designed to measure a specific physical parameter. The parameters measured will be one of the following:

Current (Amps)
Voltage (Volts)
Active power (Watts)
Reactive power (Vars)
Apparent power (VA)
Phase angle (deg)
Frequency (Hz)
Tap position
Resistance
Signal convertors (dc to dc)

There are also devices to integrate currents (Amphours) and power (Watthours) as well as temperature measuring transducers using resistance change or thermocouple voltages.

A modern development is to employ a microprocessor based circuit to derive a number of electrical parameters within one device. Such instruments can have a local liquid crystal meter display as well as an input/output port for digital communication with a data processing system.

Full details of the range of transducers available from Carrel and Carrel Ltd is presented in their data catalogues, titled Electrical Transducers T-Series and LP-Series Electrical Transducers. Information is also available on the website www.carrel-electrade.co.nz In general the T-Series transducers are housed in the traditional high standing/top terminal box used by most transducer manufacturers whilst the LP Series are housed in a modern low profile box suited to mounting in switch boxes along with modular circuit breakers and relays. Due to design refinements the LP Series transducers are more economical to produce and will eventually replace the T-Series.

In general it is advisable to use standard transducers as outlined in the data sheets. Not only is the cost minimised but one is also employing a device which is fully proven and least likely to give trouble. Non standard transducers are available, on request from Carrel-Electrade Ltd, however their cost is often higher due the extra work involved in producing them. If a large number of transducers are involved then the relative cost of producing special transducers can drop to a reasonable figure. Technical advice on all types of electrical transducers is freely available from Carrel-Electrade as they are both designers and manufacturers of all types.

DESIRABLE CHARACTERISTICS OF ELECTRICAL TRANSDUCERS

Measuring electrical quantities using transducers confers a number of advantages. They will:

(a) Provide a compact, silent unit which requires low maintenance.

(b) Convert the inputs into a different parameter such as the conversion of current and voltage signals into a power signal.

(c) Provide a signal which can be transmitted from the measuring site to one or more remote locations.

(d) Reduce the size of instrument transformers as they are not required to power a number of meters and/or long runs of cable.

(e) Provide galvanic isolation between the power system and the measuring system thereby avoiding hazardous voltages on the instruments.

(f) Limit voltage and current levels thereby protecting the measuring equipment.

(g) Change the response time of signals and provide filtering, averaging and removal of undesirable parts of the signal.

(h) Provide a feedback signal for a control system.

(i) Allow mathematical operations such as addition, subtraction, integration, rooting and squaring to be performed on system parameters.

SELECTION OF ELECTRICAL TRANSDUCERS

Performance and cost of transducers are linked. At the design stage savings can be made by matching the capabilities of transducers to the needs of the system, using performance data published in the data catalogues.

The important criteria to be considered are:

<u>a. Type of transducer</u>

The exact type of transducer should be matched to the purpose of the measurement. The different types of transducer will be considered later in their separate sections where it will be seen that certain types are used for certain purposes.

<u>b. Accuracy</u>

Most transducers are accurate to Class 0.5, which means that they can deviate from the true reading by up to 0.5% of the output range. As an example, if the output is from 4 to 20mA, then the range is 16mA and the actual deviation from the correct reading could be as much as "0.08mA. This scale of accuracy is acceptable for most measurements. When a greater accuracy is required Class 0.2 transducers are available, generally at a greater cost. There is little point in overspecifying the accuracy of a transducer in situations where that accuracy is not required or is wasted. Transducer users should also note that an accuracy figure quoted for a transducer may not necessarily represent the true absolute error at that point. The main international standard used to specify transducers,IEC 60688, defines the error as that occurring at certain rigidly fixed test conditions of temperature, frequency and power supply. When these conditions change further additional errors are permitted which could accumulate into a much larger absolute error. In practice the errors may tend to cancel and the situation may be partially corrected.

<u>c. Range</u>

As the accuracy of a transducer is specified as a percentage of the output range the designer should try to cover as much of that range as possible to preserve the accuracy. A common fault is to oversize current transformers for safety or to allow for future increases in load. Fitting CTs that are double the currnet capacity will effectively change a Class 0.5 transducer to a Class 1. It is worth noting that transducers are required to work to 120% of their nominal capacity so that one does not have to worry about small overloads. It is far more likely that an over range reading will adversely affect part of the reading system such as a data logger or PLC and these should be chosen accordingly.

d. Temperature

The operating temperature range of the transducer should include that of the panel in which it is installed when the panel is fully operational under the most extreme possible environmental conditions.

e. Robustness

The ability of the transducer to survive abuse needs to be considered. The abuse can be mechanical, such as vibration, or electrical, such as overloads and surges. Under these conditions it must also be determined whether the transducer is likely to affect other equipment.

f. Safety

A transducer must not be a hazard to other equipment or to personnel. It should not produce high voltages or currents even under fault conditions. A high potential on any input must not be conveyed to an output. In practice the galvanic separation of input and output circuits are tested for breakdown by applying a high potential (usually 4kVac) between them for a certain period (usually 1 min).

g. Electromagnetic compatibility

A transducer must not affect or be affected by other equipment due to mutual interference signals.

h. Housing

The type of enclosure housing the transducer should be compatible with the panel construction methods employed. Most transducers are housed in compact plastic cases suitable for mounting on DIN type 35 rail.

THE INTERNATIONAL STANDARD SPECIFICATION

All transducers should conform to a specified standard. The internationally accepted standard for electrical transducers is IEC 60668, titled "Electrical measuring transducers for converting a.c. electrical quantities to analogue or digital signals". The standard specifies how transducers should be labelled, how their accuracy is determined and how they should perform under both normal and abnormal operating conditions. Large specifiers of electrical transducers will find it advantageous to consult the latest copy of this standard obtainable from their local standards association or from the IEC.

IEC 60668 has a number of characteristics which should be noted as they often lead to confusion when determining accuracy. As opposed to other standards, such as those for kilowatt hour meters, IEC 60688 refers to all errors as a percentage of the full range (or span) of the instrument and not as a percentage of the reading. As a consequence relative errors at low values of reading may be higher than anticipated hence the previous recommendation to work close to the top of the range as possible. It is also worth noting that the specified accuracy is tested under a strict set of conditions. Further variations in accuracy are permitted as working conditions deviate from these set values. The following variations of basic accuracy are permitted across specified ranges of conditions.

Auxiliary supply voltage variation	50%
Auxiliary supply frequency variation	50%
Environmental temperature variation	100%
Input frequency	100%
Input voltage	50%
Input current	100%
Power factor	50%
Output load	50%
Input waveform distortion	200%
External magnetic field	100%
Current balance	100%
Interaction between internal elements	50%
Self heating	100%
Common mode voltages on output	100%
Series mode interference	100%

Theoretically all these additional errors could be cumulative leading to a large absolute error. In practice some of these errors tend to cancel leaving a less serious situation. Nevertheless users should be aware that they can exist and make suitable allowance for them.

INPUTS

Carrel-Electrade transducers are produced with those standard inputs most likely to be encountered in practice. Non standard inputs should be avoided as they generally involve increased cost and manufacturing delay.

a. AC currents

The standard current inputs are for nominal inputs of 1 Amp or 5 Amps, in line with common standards for current transformer secondaries. All ac current circuits are galvanically isolated from each other and from other circuits in the transducer thus allowing them to be earthed at a single point as is good practice.

b. AC voltages

Standard transducer voltages are those most commonly found on power systems such as 110V and 230V on single phase systems and 63.5V, 110V, 230V and 400V on three phase systems. These standard voltages may differ slightly from country to country. Multiple voltage inputs to a transducer are galvanically isolated from the other circuits in the transducer, but not from each other where there may be a high impedance common connection. The fault current likely to flow through this common connection is greatly limited by the high impedance (usually about 1mA).

c. DC inputs

There are no particular standard dc inputs although current values greater than 5A would be taken from a shunt with 50mV, 75mV or 100mV rating and voltages greater than 600V would be taken from a voltage divider with an output of 5V or 10V. Most dc transducers have galvanic isolation between input and output and can be used to not only alter the nature of the signal but also to remove troublesome common mode voltages such as from a shunt.

d. Notes on inputs

Transducers should resist damage from abnormal inputs caused by overloads or faults on the system. In general current inputs should be able to resist a continuous level of 2 times the nominal level or a short-term fault level of 20 times the nominal current for a period of up to 3 seconds. The voltage inputs should resist a continuous level of 1.2 times the nominal input or a fault level of 1.5 times the nominal for up to 10 seconds.

The inputs tend to load the source of input signals and where this source is from instrument transformers the ratings of the transformers must not be exceeded. The only transducers presenting a substantial input load are self powered transducers. Other types of transducers have very low input loads and are unlikely to present this problem. Transducers are often used to reduce the load on current transformers especially where there are a number of meters to be read and long runs of secondary side cabling.

OUTPUTS

A number of standard outputs are employed by transducers. In general these are dc currents or voltages or some form of digital signal.

a. Current driven outputs

A current driven output has a dc current which is independent of the value of load resistance thus making the output independent of variables such as meter and cable resistances. Meters in the system are dc current types and are series connected. In practice this load can vary from zero Ohms up to a limit which corresponds to a safe terminal voltage at the transducer (usually 15V for C&C transducers).

The following standard types are available:

i. 0 to 20 mA outputs (favoured by European transducer suppliers). An accurate full range output of 20 mA should be maintained up to the load limit specified by the manufacturer (750Ω for C&C transducers) This type of output is the least likely to suffer from interference and should be used where this problem is to be avoided. As the zero of the scale is also a natural zero the electronic design is simpler and less inclined to drift. An advantage of this type of output is the ability to present a negative output as is required by some power transducers. Such an arrangement is useful where CTs have been connected back to front as the transducer will still read, albeit negatively. DC meters used with 0 to 20 mA outputs are robust and well priced due to the lack of zero offset required.

ii. 0 to 10 mA outputs are favoured by many power supply authorities and are similar to the 0 to 20 mA.

iii. 4 to 20 mA outputs have a range which starts from a zero equal to 4 mA (hence known as a "live zero" type). This practice is favoured in North America and is very widely used around the world. Most instrumentation systems support it and it is mandatory for two wire transducers. A two wire system works on a device which draws dc power from the same pair of wires as the signal hence the need to pass a certain amount of current (4mA) at the zero to maintain the working of the electronic circuitry. An advantage of this type of operation is that a total loss of signal is an immediate indication that something is wrong with the transducer or its signal path. The disadvantage of this type of output is that negative outputs are difficult to accommodate, the zero more likely to drift and the active span is effectively reduced by 4 mA. Meters to measure 4 to 20 mA are generally more expensive than simpler natural zero types. Transducers with 4 to 20mA outputs require an external power source, to supply the 4mA at zero input. They can only be made self powered if the response near zero is disregarded or suppressed as in "window" transducers.

b. Voltage driven outputs

Voltage referenced outputs maintain a voltage against a variable resistance load within the limits of a certain maximum drawn current. Multiple meters in the output are placed in parallel. Standard ranges of 0 to 5V and 0 to 10V are available. Voltage referenced inputs are increasingly found on electronic devices such as digital meters, data loggers and logic controllers.

c. Comparison of current and voltage output types

Where the choice is available current outputs are preferred to voltage outputs as they are much less affected by external influences. Voltage outputs are sometimes affected by wiring resistances and should not be fed over large distances. Due to the high input impedance of typical voltage inputs the possibility of induced and reflected signals are greater than with lower impedance current inputs. The electronic circuitry of transducers with a voltage output usually involve the common rail of the power supply. Interference signals on this output are conducted to the common rail where they unduly influence the inputs to amplifiers. Current output circuits can be produced which do not involve this rail and hence avoid the problem.

The use of voltage outputs is unavoidable in cases where the associated instrumentation will not accept current inputs or where there is a clash in ground connections necessitating a parallel connection rather than a series connection.

d. Further notes on transducer outputs

To protect personnel and equipment the voltage and current levels at an output must be limited to a safe level, generally accepted as a voltage of below 32Vdc and twice the rated current. It must also be possible to open circuit or short circuit any output without endangering any person or part of the system including the transducer itself.

The output of a transducer must be capable of responding rapidly to changes in the input. The usual response time is 250 milliseconds for a change of 90% of the output which is equivalent to 99% in 500ms. Faster responses than this are possible and are available as a special unit.

The output must also have as little ac ripple superimposed on it as possible. The maximum peak to peak ripple allowed on an output signal must not be more than twice the class accuracy of the transducer, in other words less than 1% of the full scale output in a class 0.5 transducer.

Response time and ripple are inter-related and it is often not possible to improve one without degrading the other. Units incorporating improved output filtering are available which can offer better performance and improved trade off of response time and output ripple.

AUXILIARY POWER SUPPLY

The electronic circuitry within the transducer requires a source of electrical power which may sometimes be taken from an input, but is better taken from a separate power supply so as not to affect any input levels. This supply can be ac or dc. AC power supplies use a transformer to step down the voltage and to provide galvanic isolation. To provide this sort of isolation with dc supplies requires an electronic switching circuit to convert the dc into a high frequency ac signal which is then fed to a transformer.

Of these two types of supply the ac supply is to be preferred as it is simpler and avoids the potential interference introduced by the switching circuit. Use dc switching supplies only when this is the only reliable source of power.

Loop powered transducers are a cost effective means of supplying dc power to a transducer where isolation is not required between supply and output. The output of this type is always 4 to 20 mA. The transducer is connected via its signal wires to a low voltage dc supply and acts as a current regulator in proportion to measured signal. As long as a certain specified voltage remains at the transducer terminals the rest of the voltage can be dropped across series meters and cabling in the two wire loop between the transducer and the power supply.

CURRENT TRANSDUCERS

Two basic types of current transducers are recognised.

a. Average reading types

Average reading current transducers assume that the measured current waveform is an undistorted sine wave. In most cases this is a valid assumption. These transducers are simple, economical and reliable. The following models of average reading current transducer are available from C&C:

i. Models T-IS/LP-IS are self powered transducers which do not require an external power source as they take their power from the current signal. As they are self powered they do not come in a live zero (4 to 20 mA) version.

ii. Models LP-ISX3 is a triple version of the LP-IS with three separate transducers housed in one enclosure.

iii. Models T-IP/LP-IP are separately powered transducers which are used if a 4 to 20 mA output is required or if the burden on the current source is required to be low.

iv. Models T-IL/LP-IL are loop powered (two wire type) transducers which require an external dc power source. They only provide a 4 - 20 mA response.

v. Model T-ILE is a loop powered transducer with an integral current transformer. This a highly economical transducer to employ as the cost of a separate CT is covered by the unit which also occupies much less space than a separate CT and transducer.

vi. Model LP-ID is a microprocessor based transducer with a Modbus output on a twisted pair RS 485 bus system.

b. RMS reading type

Non-linear loads such as rectifiers, variable speed drives, computer supplies and other types of electronic circuits can distort the current waveform and make the wave shape non-sinusoidal. Under these circumstances an average reading transducer may not give an accurate reading and a root mean square (rms) reading type of transducer must be used.

The following type is available from C&C.

i. Model T-IRMS is a separately powered rms responding current transducer which is similar to the T-IP transducer in that it presents low input load and can provide any type of output.

VOLTAGE TRANSDUCERS

As with current transducers two basic types of voltage transducers are recognised.

a. Average reading types

Average reading voltage transducers also require a sinusoidal input waveform. The following types are available from C&C.

ii. Models T-VS/LP-VS are self powered voltage transducers which take their power from the input voltage signal. Not available in a 4 to 20 mA version.

iii. Model LP-VSX3 is a triple version of the LP-VS with three separate transducers in one enclosure.

iv. Models T-VP/LP-VP are separately powered transducers used for 4 to 20 mA outputs and where a low input load is desired.

v. Models T-VL/LP-VL are loop powered (two wire) transducers which require an external source of dc power. Only available with 4 - 20 mA response.

vi. Models T-VP/LP-VP and T-VL/LP-VL are also available in suppressed zero versions, also commonly known as window type. This type of transducer is only active in the top part of the voltage range thus giving a more sensitive reading concentrated in an area which is deemed to be important. A typical transducer for a working voltage of 110V would read from 90V to 130V.

b. RMS reading type

Distorted voltage waveforms are less commonly encountered than distorted current waveform however under these circumstances an rms transducer is available from C&C.

i. Model T-VRMS is a separately powered root mean square responding voltage transducer.

POWER TRANSDUCERS

Power transducers combine voltage and current signals to produce a signal proportional to the type of power being measured. Power transducers measure either active power (Watts), reactive power (Vars) or apparent power (VA).

(a) Active power (Watt) transducers

The active power in a load represents the energy being converted into non electrical forms such as heat, light and mechanical work. It is represented by the voltage across the load multiplied by the in-phase component of the current through the load. Active power transducers obtain a power signal from the input current and voltage signals by passing them through an electronic multiplier. When this power signal is averaged it represents the true power independent of phase angle and wave shape. Single phase transducers have a single multiplying element whilst three phase transducers have up to three multiplying elements depending on their type. A variety of power transducers are available to suit various purposes. The simpler types, whilst they are cheaper in price, often rely on some assumption being made which affects their accuracy. The following types are available from Carrel-Electrade

i. T-1W1/LP-1W1 are single phase power transducers reading from corresponding voltage and current signals. Economical versions, types T-1W1S/LP-1W1S, are in a more compact housing and have a unidirectional output.

ii. T-1W3/LP-1W3 are three phase power transducers which assume that the system measured presents a balanced load ie all three voltages and currents are the same. This assumption is valid for certain devices such as three phase electric motors. The transducers have one multiplying element which measures the power on one of the phases and assumes that the other two phases are the same. A single current and three phase to phase voltage inputs are required. These transducers permit a considerable economy as they are not only less expensive than other types but also require only one CT. Economical versions of these transducers, types T-1W3S/LP-1W3S, are in a compact housing and have a unidirectional output.

iii. T-1W4/LP-1W4 are single element three phase power transducers for balanced loads. They are similar to the 1W3 version but are intended for apllications where only a phase to neutral voltage signal is available. Economical versions, types T-1W4S/LP-1W4S are in a compact housing and have a unidirectional output.

iv. T-2W3/LP-2W3 are three phase power transducers for unbalanced loads. They contain two multiplying elements which measure power using the well known Two Wattmeter method of power measurement. In this method it is assumed that current flows only in the three phase wires and does not return down a neutral wire. Such a system is referred to as a three wire system. Transducers based on this method require only two current inputs and are able to work when the supply and load is unbalanced. High voltage transmission circuits are often three wire systems and this transducer offers an economical means to measure power (on such systems) as it requires only two VTs and two CTs. The quality of instrument transformers used with this transducer is important as there is an inherent phase shift between current and voltage inputs which accentuates any inaccuracy in the transformers.

v. T-3W4 is a three phase power transducer for unbalanced loads and supplies, with an active neutral (four wire system). The circuitry contains three multiplying elements, one for each phase (Three Wattmeter method). As each phase is monitored separately the transducer provides a measurement which is independent of any assumptions and can be used on any system. The main disadvantage of using this transducer is the relatively higher cost and the need for three CTs and VTs. This transducer is most often used at mains potential where no VTs are required and the CTs are relatively inexpensive.

vi. T-2.5W4/LP-2.5W4 are three phase power transducers for unbalanced loads and a balanced supply, with an active neutral. The circuitry contains two multiplying elements with an arrangement to permit the inclusion of a third current circuit. This type of transducer is a substitute for a proper three element transducer. Carrel-Electrade have included them in their range so as not to disadvantage themselves against competitors carrying this type instead of three element types. The use of these so called "Two and a half element" transducers can only be justified when cost is of overriding importance.

(b) Reactive power (Var) transducers

Reactive power transducers measure the quadrature component of the instantaneous power, which is the product of the voltage and the reactive (quadrature) current. Reactive power does no work in the load and represents the instantaneous power stored in the reactive components (inductance and capacitance) of the load. Although this current component performs no useful work in the load it still increases the overall current level in the supply network and thereby causes increased transmission losses. For this reason most power suppliers try to minimise the reactive power flowing in their systems and need to measure this quantity.

The range of reactive power transducers is similar to the active power transducers except that internal voltage signals are displaced by 90E before being applied to the multipliers. These displaced voltages are derived in a number of ways which tend to restrict the reading conditions. Reactive power can be inductive (lagging) or capacitive (leading). Carrel-Electrade use the convention that lagging signals are positive and leading signals are negative. The following reactive power transducers are available from Carrel-Electrade.

i. T-1V1 is a single phase reactive power transducer. To achieve the 90E internal phase shift a capacitive phase shifting circuit is used. Unfortunately this circuit is also frequency sensitive which means that the transducer is only accurate at one particular supply frequency. Due to this restriction this transducer should only be used where no alternative is suitable.

ii. T-1V4 is a three phase reactive power transducer for balanced loads where one current and only a single matching phase to neutral voltage is available. The internal circuitry is the same as the single phase transducer and is also restricted to a particular frequency. Due to this restriction this transducer should only be used where no alternative is suitable.

iii. T-1V3/LP-1V3 are single element three phase reactive power transducers for balanced loads where one current and three phase voltages are available. The necessary 90E phase shift is given to the voltage signal by taking this voltage from the two phases opposite the current phase. As the phase shift relies on the symmetry of the three phase supply this supply must be balanced, however the shift is independent of frequency unlike the single phase types. Economical versions, types T-1V3S/LP-1V3S, have a compact enclosure and have a unidirectional output.

iv. T-2V3/LP-2V3 are two element three phase reactive power transducers for unbalanced loads on three wire systems with balanced voltages. They require two current signals and is independent of supply frequency.

v. T-3V4 is a three element three phase reactive power transducer for unbalanced loads on four wire systems with balanced voltages. It requires three current signals and is independent of supply frequency.

vi. T-2.5V4/LP-2.5V4 are two element three phase reactive power transducers for unbalanced loads on four wire systems with balanced voltages. They represent a cheaper compromise for four wire systems.

(c) Apparent power (VA) transducers

The apparent power of a load is calculated by multiplying the rms voltage across the load by the rms current through the load without regard to the phase angle between them. It represents the power present if the power factor was unity. Apparent power is useful as a measure of stress on components that are affected by both current and voltage such as generators, motors, transformers and cables.

To obtain an apparent power signal one must first obtain dc signals proportional to voltage and current and then multiply them. In most cases voltage waveforms are less distorted than current waveforms so C&C transducers multiply the averaged voltage signal with the rms current signal. Due to the lack of phase angle influence VA transducer outputs are always unidirectional. The following VA transducers are available from Carrel-Electrade.

i. T-1VA1 is a single phase VA transducer.

ii. T-1VA3 is a three phase VA transducer for balanced loads on a balanced three or four wire system.

iii. T-1VA4 is a three phase VA transducer for balanced loads on a balanced four wire system where only a single phase to neutral voltage is available.

iv. T-2VA3 is a three phase VA transducer for unbalanced loads on a balanced or unbalanced three wire system ie no neutral.

v. T-3VA4 is a three phase VA transducer for unbalanced loads on a balanced or unbalanced four wire system ie with neutral wire.

(d) Universal (multifunction) transducers

Using microprocessor techniques a transducer can be produced which will perform a large number of functions. Thus one device, with one set of three phase current and voltage inputs can provide a full range of electrical measurements including currents, voltages and power measurements as well as frequency and power factor. In addition integral functions can be performed to obtain energy quantities such as kWhrs. Data logging and storage of data is also provided is some cases as well as the recording of maximum and minimum quantities.

C&C have a number of such devices available, with or without liquid crystal displays to provide local indication of electrical measurements.

(e) Some notes concerning power transducers

(i) Power flow and polarity

Power flow in a system is positive when power flows from the generation source to the load. At a certain point in a complicated system the direction of power flow could be positive or negative as conditions change. Under these circumstances power transducers need to have a bidirectional output, which is usually achieved by having an output which can go positive or negative (bipolar output). This method works well when the output has a measurement zero which is also an output zero for example a 0 to 20mA output which then becomes a -20 to 0 to +20mA output. Live zero transducers, such as those with 4 to 20mA outputs, cannot go negative and hence require the zero to be placed somewhere in the middle of the working range. Often the likely power flow in one direction is less than that in the opposite direction so that the zero does not have to be placed in mid range. In this case the zero is always placed somewhere in the lower half of the scale. It is normal practice to have equal sensitivity on both negative and positive power ranges. Although it is possible to have transducers where one polarity is more sensitive than the other this practice is not encouraged.

(ii) Connections

All current and voltage inputs to a power transducer must be correctly placed for a correct output to be obtained. If voltage or current signals are reversed then the output will be reversed. If a single input is reversed compared to the other inputs then the output is reduced or even lost completely. If the incorrect voltage and current signals are aligned then the situation becomes complex and difficult to interpret. Carrel-Electrade have produced a leaflet entitled "T-series power transducers - Installation instructions" which details how to go about ensuring that power transducers are correctly connected.

In cases where all the CTs have been connected in the reverse direction reversing the output will only correct the situation if the output is truly bidirectional. In the case of live zero transducers such as those with 4 to 20mA outputs the output will not go below the live zero and may even appear to be not working. In this case the CT leads must be reversed, an action which often requires the power to be switched off, which may not be convenient at the time.

(iii) Integration

Power transducer signals can be time integrated mathematically by an additional circuit to yield units such as Joules or kWhrs from Watt signals. This integrating unit can be built into certain of the transducers as an integral unit.

(iv) Range specification

Power transducers can be set to any input range and do not necessarily have to be specified to VI for a single phase or 1.732VI for three phases (where V and I are nominal voltage and current). However the greatest accuracy will be achieved in the region of these values and it pays to choose a range which has been rounded off close to them. Carrel-Electrade prefer the following standard values for three phase power transducers.

V	**I**	**1.73VI**	**Preferred Values**
110V	1A	190.53W	200W
110V	5A	952.63W	1000W
400V	1A	692.82W	700W
400V	5A	3464.10W	3500W

Whilst the value of 110V is universal for VT secondaries some countries use 380V or 415V for 3 phase supplies. These values are close enough to 400V as to make no difference when using standard transducers.

In some cases transducers are specified in terms of the actual power units in the system being measured. This action requires a knowledge of the voltage and current transformer ratios. Transducers such as these are confined to a certain position within a system. It is often more convenient to use the preferred values and multiply the outputs by the relevant VT and CT ratios to obtain the true readings. With this method transducers can be interchanged easily and a minimum of spare transducers carried to cover eventualities.

When the CTs in a system have been over sized it may be necessary to greatly increase the sensitivity of a transducer to fully cover the power range, with a subsequent loss of overall accuracy. This situation should be avoided by choosing CTs that match the capacity of the system.

(v) Combining readings

It is often necessary to sum a number of power readings from different transducer. With transducers whose outputs are galvanically isolated from each other the outputs can be combined by putting them in parallel for current outputs or in series for voltage outputs. The sensitivity of the transducers must be the same with the same input to output ratios. Where this is not the case a summing circuit must be used.

PHASE ANGLE TRANSDUCERS

Phase angle transducers provide a signal which is linearly proportional to the phase angle between a voltage and a current in a power system. This type of transducer is often called a power factor transducer, which is technically incorrect as power factor is proportional to the cosine of the phase angle and as such is non linear. Many operators prefer the phase angle to be expressed as a power factor, which is easily accomplished using specially scaled moving coil meters. Other types of meters and systems require computation to convert phase angle to power factor. Phase angle transducers have limitations of their use which should be noted. Most units only work off one phase and are only valid for balanced three phase systems. A certain minimum current level is needed to obtain a valid reading and ambiguous readings are likely when these levels are too low. Serious operators who wish to monitor reactive currents in their system are advised to employ reactive power transducers rather than phase angle transducers.

The range of phase angle chosen depends on the behaviour of the system being measured. As with all transducers one should attempt to match the transducer range to the operating range of the system. For systems which contain inductive elements only a range of -60° to 0° (Pf 0.5 lagging to Pf 1) is a practical one to choose. For stability reasons many power systems are operated slightly lagging and are unlikely to go very much leading. A good range for this type of system would be from -60° to 0° to $+30^{\circ}$ (Pf 0.5 lagging to Pf 1 to Pf 0.86 leading). Where the system can go quite heavily leading the range -60° to 0° to $+60^{\circ}$ (Pf 0.5 lagging to Pf 1 to Pf 0.5 leading) is the best choice, especially with bidirectional outputs such as -20 mA to 0 to +20 mA.The following phase angle transducers are available from Carrel-Electrade.

i. T-PF1 is a single phase phase angle transducer. Certain range types require the use of a quadrature phase shifter which may restrict the frequency range of operation.

ii. T-PF3 is a three phase phase angle transducer for balanced loads. A current signal and a voltage signal from the two opposite phases is required.

FREQUENCY TRANSDUCERS

Frequency transducers provide a signal which is proportional to the frequency of a supply (mains) voltage. As power frequencies are centred on certain standard values it is normal practice to produce these transducers as suppressed zero (window) types with the standard frequency at the centre of the range. For supply frequencies of 50 Hz the most popular ranges are 45 - 55 Hz or 48 - 52 Hz depending on the stability of the system. As with most window transducers the absolute accuracy remains the same whilst the relative accuracy changes with the width of the window. Carrel-Electrade supply either the T-FM or the LP-FM. Both units are controlled by a quartz crystal oscillator for stability.

SIGNAL CONVERTORS

Signal convertors exist for ac and dc inputs. The term ac signal convertor usually refers to a transducer for low level ac signals whilst dc signal convertors handle the whole range of dc voltages and currents from low levels to high levels. In general signal convertors change the input into a standard transducer type output and provide galvanic isolation between input and output. They are useful when one type of transducer signal needs to be changed into a different type of signal or if the point of measurement is at a different potential from that of the instrumentation. In a system with conflicting potentials, problems can be caused by unwanted stray currents and short circuits. By placing one or more signal convertors at strategic points in the system this conflict can be removed. Signal convertors are also useful for isolating parts of the system likely to carry high potentials under fault conditions such as during lightning strikes. When they are used in conjunction with surge diverters hazardous transients can be prevented from entering vulnerable parts of the system.

Carrel-Electrade supply a number different types of signal convertors.

i. T-CDV/T-CDI range of signal convertors have two separate printed circuit boards for input and output signals. Each board has its own power supply to maintain the isolation. A modulated light beam passes the signal between the two boards to maintain a very high level of isolation between input and output. The following variations are available with the usual range of output values including bipolar types.
   - T-CAI - low level ac current input
   - T-CAV - low level ac voltage input
   - T-CDI - dc current input
   - T-CDV - dc voltage input

ii. T-CDU is a low cost dc signal convertor for less exacting applications. It has a single pc board with optocoupler isolation and a unipolar output. An auxiliary supply is required.

iii. T-CDL is a dc signal convertor with a self powered input and a loop powered output. Designed primarily for 4 to 20mA input signals it is most useful for isolating a large number of such signals at a comparatively low cost. Outputs of 4 to 20 mA (2 wire system) or 0 to 5/10 V (3 wire system) are available.

iv. LP-CDU is a dc signal convertor with current or voltage input and 4 - 20mA dc output. A dc or ac auxiliary supply is required. This convertor has a very fast response time which makes it suitable for protection and control circuits.

TAP POSITION AND RESISTANCE TRANSDUCERS

(a) Tap position transducers

Tap position transducers convert the signal from a sensor on a power transformer tap changer mechanism into a standard transducer signal. Carrel-Electrade produce two different types of transducer to accommodate the two basic types of sensor used for this purpose.

i. T-TPA is a tap change transducer for ac signals from a variable reluctance sensor. This type of sensor has a sensor coil which moves in a magnetic field set up by a set of coils energised by a ac voltage. The voltage induced in the moving coil is governed by the position of the coil. As the energising voltage also affects the signal this signal varies in proportion to any changes in supply voltage. The transducer contains an analogue divider circuit which divides the sensor signal by the energising voltage to obtain a signal independent of supply voltage fluctuations. Both inputs are isolated from the output. This transducer plus suitable metering is widely used to replace obsolete cross field instruments and is not likely to be used in any new systems.

ii. T-TPR is a tap change transducer working off a potentiometer attached to the tap changer mechanism. This system is suitable for any new designs as well as to replace existing cross field instruments. The transducer places a regulated dc voltage across the potentiometer and senses the voltage present at the moving wiper of the potentiometer. The transducer provides galvanic isolation between the potentiometer and the output circuit.

(b) Resistance transducer

The T-R transducer provides a signal linearly proportional to a external resistance by injecting a regulated current into the resistor and measuring the voltage dropped across it. It is used with positional transducers and other such variable resistance devices. The resistance measured must not be carrying current from any other source at the time of measurement.

TEMPERATURE TRANSDUCERS

Temperature transducers convert the signal from a sensor into a standard transducer signal linearly proportional to temperature. Carrel-Electrade produce two basic types of temperature transducer.

(a) Resistive types

Resistive temperature transducers work in conjuction with a resistor which changes its electrical resistance in response to temperature changes. The universal standard sensor resistor, named the Pt100 type, consists of a fine Platinum metal wire (or film) with a nominal resistance of 100Ω at 0EC. Other resistance values (such as 1000Ω) and materials (such as Nickel) are used, however the Pt100 is by far the most common sensor available.

Resistive temperature transducers need to compensate for the resistance of the connecting leads between the sensor resistor and the transducer. To perform this function the connection requires a set of conductors of equal matched resistance in a common cable. Resistive transducers do not have an entirely linear response and the better types of transducer correct for this non-linearity. Carrel-Electrade produce the following transducers.

i. T-TR is a resistive temperature transducer which requires an auxiliary supply. The sensor is not isolated from the output. The three wire method of lead compensation
ii. is employed and the input signal is compensated for non linearity. All the usual standard transducer outputs are available.

iii. T-TRL is a loop powered resistive temperature transducer with three wire lead compensation and linearisation. The unit requires an external dc supply. There is no galvanic isolation between the input and the output.

iv. LP-TRD is a digital resistive temperature transducer with a Modbus RS485 output. It exhibits better than average linearisation due to a double analogue/digital compensation method

(b) Thermocouple transducers

A thermocouple is a device, consisting of two metals in contact, which generates a low level voltage when a temperature difference occurs across it. A thermocouple transducer amplifies this low level voltage and converts it into a standard transducer signal. When measuring a temperature one end of the thermocouple must be kept at that temperature while the other end is kept at a standard temperature usually 0EC. In practice this standard temperature is difficult to maintain so the transducer measures the ambient temperature at the end of the thermocouple and compensates the signal for the difference from the standard value. This technique is known as cold junction compensation. Thermocouple signals are not linear and must be corrected for better accuracy. Carrel-Electrade has one model of thermocouple transducer, the T-TTH, which has cold junction compensation, linearisation and is energised from an auxiliary supply. Inputs for thermocouples of the K and J types are routinely available and other types can be supplied on request.

(c) Some notes on temperature measurement

Temperature measurements are often made difficult by the wrong choice of sensor. In general whilst thermocouples are not as accurate as Pt100 sensors they are smaller and less expensive. Pt100 sensors are best used at fairly low temperatures (<300EC) whilst thermocouples are best used at higher temperatures. At very high temperatures (>600EC) type K thermocouples should be used rather than type J thermocouples.

Thermocouple transducers should to be sited in a cool position which usually neccessitates placing them remote from the measurement point and running special thermocouple compensating leads between the sensor and the transducer. These leads are made of similar material to the thermocouple pair and effectively extend the thermocouple all the way back to the transducer to ensure that the cold junction compensation works correctly. Compensation leads are relatively expensive and their cost must be balanced against the low cost of the thermocouple sensor itself.

INTEGRATORS

Integrators are devices which derive a summated time integral of an input. Where this input is a signal from a transducer measuring some type of rate related quantity the integral has real meaning. A good example of a rate related quantity is that of the signal from a power transducer which, when integrated, becomes a measure of the total energy in Joules, kWhrs or similar such units. Another example is using the signal from a dc current transducer or a dc shunt to produce a measure of electric charge in Coulombs or Amphrs. Similarly transducer signals for speed or rate of use can be integrated to provide a quantity measure in many processes.

The input to an integrator can be any dc signal linearly proportional to the required rate measurement. The output is usually presented as pulses of some type which can be used to advance a counting device. The pulse rate is proportional to the input signal. The most commonly used output is a set of relay contacts which can be used to operate a counter. This type of output has the advantage of galvanic isolation coupled with the ability to accept all sorts of voltages and currents including ac quantities. The main disadvantage of using a relay is its limited speed of operation (<1Hz) and limited physical life. Under certain circumstances open collector transistors and optocouplers can also be used.

Besides the integrator fitted to certain power transducers Carrel-Electrade provide an individual integrator, the T-INTP, which has a dc input, pulsed output and requires an auxiliary supply. Most integrators are produced to customer's individual requirements.