· 22 · Power System Measurements

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22.1 INTRODUCTION

The accurate measurement of the voltage, current or other parameter of a power system is a prerequisite to any form of control, ranging from automatic closed-loop control to the recording of data for statistical purposes. Measurement of these parameters can be accomplished in a variety of ways, including the use of direct-reading instruments as well as electrical measuring transducers.

Transducers produce an accurate d.c. analogue output, usually a current, which corresponds to the parameter being measured (the measurand). They provide electrical isolation by transformers, sometimes referred to as 'Galvanic Isolation', between the input and the output. This is primarily a safety feature, but also means that the cabling from the output terminals to any receiving equipment can be lightweight and have a lower insulation specification. The advantages over discrete measuring instruments are as follows:

a. mounted close to the source of the measurement, reducing instrument transformer burdens and increasing safety through elimination of long wiring runs

b. ability to mount display equipment remote from transducer

c. ability to use multiple display elements per transducer

d. the burden on CT's/VT's is considerably less

Outputs from transducers may be used in many ways – from simple presentation of measured values for an operator, to being utilised by a network automation scheme to determine the control strategy.

22.2 GENERAL CHARACTERISTICS

Transducers may have single or multiple inputs and/or outputs. The inputs, outputs and any auxiliary circuits will all be isolated from each other. There may be more than one input quantity and the measurand may be a function of one or more of them.

Whatever measurement transducer is being used, there will usually be a choice between discrete and modular types, the latter being plug-in units to a standard rack. The location and user-preferences will dictate the choice of transducer type.

22.2.1 Transducer Inputs

The input of a transducer is often taken from transformers and these may be of many different types. Ideally, to obtain the best overall accuracy, metering-class instrument transformers should be used, since the transformer errors will be added, albeit algebraically, to the transducer errors. However, it is common to apply transducers to protection-class instrument transformers and that is why transducers are usually characterised to be able to withstand significant short-term overloads on their current inputs. A typical specification for the current input circuits of a transducer suitable for connection to protection-class instrument transformers is to withstand:

a. 300% of full-load current continuously

b. 2500% for three seconds

c. 5000% for one second

The input impedance of any current input circuit will be kept as low as possible, and that for voltage inputs will be kept as high as possible. This reduces errors due to impedance mismatch.

22.2.2 Transducer Outputs

The output of a transducer is usually a current source. This means that, within the output voltage range (compliance voltage) of the transducer, additional display devices can be added without limit and without any need for adjustment of the transducer. The value of the compliance voltage determines the maximum loop impedance of the output circuit, so a high value of compliance voltage facilitates remote location of an indicating instrument.

Where the output loop is used for control purposes, appropriately rated Zener diodes are sometimes fitted across the terminals of each of the devices in the series loop to guard against the possibility of their internal circuitry becoming open circuit. This ensures that a faulty device in the loop does not cause complete failure of the output loop. The constant-current nature of the transducer output simply raises the voltage and continues to force the correct output signal round the loop.

22.2.3 Transducer Accuracy

Accuracy is usually of prime importance, but in making comparisons, it should be noted that accuracy can be defined in several ways and may only apply under very closely defined conditions of use. The following attempts to clarify some of the more common terms and relate them to practical situations, using the terminology given in IEC 60688.

The accuracy of a transducer will be affected, to a greater or lesser extent, by many factors, known as influence quantities, over which the user has little, or no, control. Table 22.1 provides a complete list of influence quantities. The accuracy is checked under an agreed set of conditions known as reference conditions. The reference conditions for each of the influence quantities can be quoted as a single value (e.g. 20°C) or a range (e.g. 10-40°C).

Input current	Input voltage
Input quantity distortion	Input quantity frequency
Power factor	Unbalanced currents
Continuous operation	Output load
Interaction between measuring elements	Ambient temperature
Auxiliary supply voltage	Auxiliary supply frequency
External magnetic fields	Self heating
Series mode interference	Common mode interference
External heat	

Table 22.1: Transducer influence quantities

The error determined under reference conditions is referred to as the intrinsic error. All transducers having the same intrinsic error are grouped into a particular accuracy class, denoted by the class index. The class index is the same as the intrinsic error expressed as a percentage (e.g. a transducer with an intrinsic accuracy of 0.1% of full scale has a class index of 0.1). The class index system used in IEC 60688 requires that the variation for each of the influence quantities be strictly related to the intrinsic error. This means that the higher the accuracy claimed by the manufacturer, the lower must be all of the variations.

Because there are many influence quantities, the variations are assessed individually, whilst maintaining all the other influence quantities at reference conditions.

The nominal range of use of a transducer is the normal operating range of the transducer as specified by the manufacturer. The nominal range of use will naturally be wider than the reference value or range. Within the nominal range of use of a transducer, additional errors accumulate resulting in an additional error. This additional error is limited for any individual influence quantity to, at most, the value of the class index. Table 22.2 gives performance details of a typical range of transducers according to the standard.

Accuracy Class of Transducer: 0.5				
Influence Quantity	Reference Range	Max. Error- Reference Range %	Nominal Working Range	Max. Error- Nominal Range
Input current,In	In=1A, 5A 20...120%	0.5%	0-120%	0.5%
Input voltage,Vn	Vn=50...500V 80...120%	0.25%	0-120%	0.5%
Input frequency	45...65Hz	0.5%	-	-
Power factor	Cos φ = 0.5...1	0.25%	Cos φ = 0...1	0.5%
Unbalanced current	0...100%	0.5%	-	-
Interaction between measuring elements	Current input 0...360°	0.25%°	-	-
Continuous operation	Continuous > 6h	0.5%	-	-
Self Heating	1...30min	0.5%	-	-
Output load	10...100%	0.25%	-	-
Waveform crest factor	1.41 (sine wave)	-	1.2...1.8	0.5%
Ambient temperature	0°-50° C	0.5%	-10°-60° C	1.0%
Aux. supply d.c. voltage	24...250V DC	0.25%	19V-300V	0.25%
A.C. Aux. Supply frequency, fn	90...110% fn	0.25%	-	-
External magnetic fields	0...0.4kA/m	0.5%	-	-
Output series mode interference	1V 50Hz r.m.s. in series with output	0.5%	-	-
Output common mode interference	100V 50Hz r.m.s. output to earth	0.5%	-	-

Table 22.2: Typical transducer performance

Confusion also arises in specifying the performance under real operating conditions. The output signal is often a d.c. analogue of the measurand, but is obtained from alternating input quantities and will, inevitably, contain a certain amount of alternating component, or ripple. Ripple is defined as the peak-to-peak value of the alternating component of the output signal although some manufacturers quote 'mean-to-peak' or 'r.m.s.' values. To be meaningful, the conditions under which the value of the ripple has been measured must be stated, e.g. 0.35% r.m.s. = 1.0% peak-to-peak ripple.

Under changing conditions of the measurand, the output signal does not follow the changes instantaneously but is time-delayed. This is due to the filtering required to reduce ripple or, in transducers using numerical technology, prevent aliasing. The amount of the delay is called the response time. To a certain extent, ripple and response time are interrelated. The response time can usually be shortened at the expense of increased ripple, and vice-versa. Transducers having shorter response times than normal can be supplied for those instances where the power system suffers swings, dips, and low frequency oscillations that must be monitored.

Transducers having a current output have a maximum output voltage, known as the compliance voltage. If the load resistance is too high and hence the compliance voltage is exceeded, the output of the transducer is no longer accurate.

Certain transducers are characterised by the manufacturer for use on systems where the waveform is not a pure sinusoid. They are commonly referred to as '*true r.m.s. sensing*' types. For these types, the distortion factor of the waveform is an influence quantity. Other transducers are referred to as 'mean-sensing' and are adjusted to respond to the r.m.s. value of a pure sine wave. If the input waveform becomes distorted, errors will result. For example, the error due to third harmonic distortion can amount to 1% for every 3% of harmonic.

Once installed, the user expects the accuracy of a transducer to remain stable over time. The use of high quality components and conservative power ratings will help to ensure long-term stability, but adverse site conditions can cause performance changes which may need to be compensated for during the lifetime of the equipment.

22.3 DIGITAL TRANSDUCER TECHNOLOGY

Digital power system transducers make use of the same technology as that described for digital and numerical relays in Chapter 7. The analogue signals acquired from VT's and CT's are filtered to avoid aliasing, converted to digital form using A/D conversion, and then signal processing is carried out to extract the information required. Basic details are given in Chapter 7. Sample rates of 64 samples/cycle or greater may be used, and the accuracy class is normally 0.5.

Outputs may be both digital and analogue. The analogue outputs will be affected by the factors influencing accuracy as described above. Digital outputs are typically in the form of a communications link with RS232 and/or RS485 types available. The response time may suffer compared to analogue transducers, depending on the rate at which values are transferred to the communications link and the delay in processing data at the receiving end. In fact, all of the influence quantities that affect a traditional analogue transducer also are present in a digital transducer in some form, but the errors resulting may be much less than in an analogue transducer and it may be more stable over a long period of time.

The advantages of a transducer using numerical technology are:

1. improved long-term stability
2. more accurate r.m.s measurements
3. improved communications facilities
4. programmability of scaling
5. wider range of functions
6. reduced size

The improved long term stability reduces costs by extending the intervals between re-calibration. More accurate r.m.s measurements provide the user with data of improved accuracy, especially on supplies with significant harmonic content. The improved communications facilities permit many transducers to share the same communications link, and each transducer to provide several measurements. This leads to economy in interconnecting wiring and number of transducers used. Remote or local programmable scaling of the transducer permits scaling of the transducer in the field. The scaling can be changed to reflect changes in the network, or to be re-used elsewhere. Changes can be downloaded via the communications link, thus removing the need for a site visit. It also minimises the risk of the user specifying an incorrect scaling factor and having to return the transducer to the manufacturer for adjustment. Suppliers can keep a wider range of transducers suitable for a wide range of applications and inputs in stock, thus reducing delivery times. Transducers are available with a much wider range of functions in one package, thus reducing space requirements in a switchboard. Functions available include harmonics up to the 31st, energy, and maximum demand information. The latter are useful for tariff negotiations.

22.4 ANALOGUE TRANSDUCER TECHNOLOGY

All analogue transducers have the following essential features:

a. an input circuit having impedance Z_{in}

b. isolation (no electrical connection) between input and output

c. an ideal current source generating an output current, I_1, which is an accurate and linear function of Q_{in}, the input quantity

d. a parallel output impedance, Z_o. This represents the actual output impedance of the current source and shunts a small fraction, I_2, of the ideal output

e. an output current, I_o, equal to $(I_1 - I_2)$

These features are shown diagrammatically in Figure 22.1.

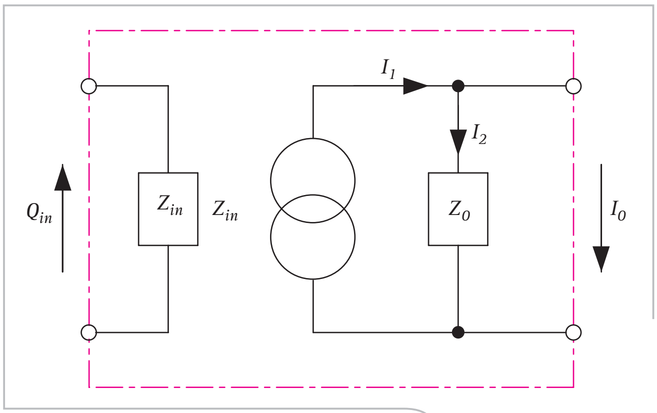


Figure 22.1: Schematic of an analogue transducer

Output ranges of 0-10mA, 0-20mA, and 4-20mA are common. Live zero (e.g. 4-20mA), suppressed zero (e.g. 0-10mA for 300-500kV) and linear inverse range (e.g. 10-0mA for 0-15kV) transducers normally require an auxiliary supply. The dual-slope type has two linear sections to its output characteristic, for example, an output of 0-2mA for the first part of the input range, 0-8kV, and 2-10mA for the second part, 8-15kV.

22.5 TRANSDUCER SELECTION

The selection of the correct transducer to perform a measurement function depends on many factors. These are detailed below.

22.5.1 Current Transducers

Current transducers are usually connected to the secondary of an instrument current transformer with a rated output of 1 or 5 amps. Mean-sensing and true r.m.s. types are available. If the waveform contains significant amounts of harmonics, a true r.m.s sensing type must be used for accurate measurement of the input. They can be self-powered, except for the true r.m.s. types, or when a live zero output (for example 4-20mA) is required. They are not directional and, therefore, are unable to distinguish between 'export' and 'import' current. To obtain a directional signal, a voltage input is also required.

22.5.2 Voltage Transducers

Connection is usually to the secondary of an instrument voltage transformer but may be direct if the measured quantity is of sufficiently low voltage. The suppressed zero type is commonly used to provide an output for a specific range of input voltage where measurement of zero on the input quantity is not required. The linear inverse type is often used as an aid to synchronising.

22.5.3 Frequency

Accurate measurement of frequency is of vital importance to transmission system operators but not quite so important, perhaps, for the operator of a diesel generator set. Accuracy specifications of 0.1% and 0.01% are available, based on percent of centre scale frequency. This means, for example that a device quoted as 0.1% and having a centre scale value of 50Hz will have a maximum error of $\pm 50mHz$ under reference conditions.

22.5.4 Phase Angle

Transducers for the measurement of phase angle are frequently used for the display of power factor. This is achieved by scaling the indicating instrument in a non-linear fashion, following the cosine law. For digital indicators and SCADA equipment, it is necessary for the receiving equipment to provide appropriate conversions to achieve the correct display of power factor. Phase angle transducers are available with various input ranges. When the scaling is -180°...0°...180°, there is an ambiguous region, of about ±2° at the extremes of the range. In this region, where the output is expected to be, for example, −10mA or +10mA, the output may jump sporadically from one of the full-scale values to the other. Transducers are also available for measurement of the angle between two input voltages. Some types of phase angle transducer use the zero crossing point of the input waveform to obtain the phase information and are thus prone to error if the input contains significant amounts of harmonics.

Calculating the power factor from the values of the outputs of a watt and a var transducer will give a true measurement in the presence of harmonics.

22.5.5 Power Quantities

The measurement of active power (watts) and reactive power (vars) is generally not quite as simple as for the other quantities. More care needs to be taken with the selection of these types because of the variety of configurations. It is essential to select the appropriate type for the system to be measured by taking into account factors such as system operating conditions (balanced or unbalanced load), the number of current and voltage connections available and whether the power flow is likely to be 'import', 'export', or both. The range of the measurand will need to encompass all required possibilities of over-range under normal conditions so that the transducer and its indicating instrument, or other receiving equipment, is not used above the upper limit of its effective range. Figure 22.2 illustrates the connections to be used for the various types of measurement.

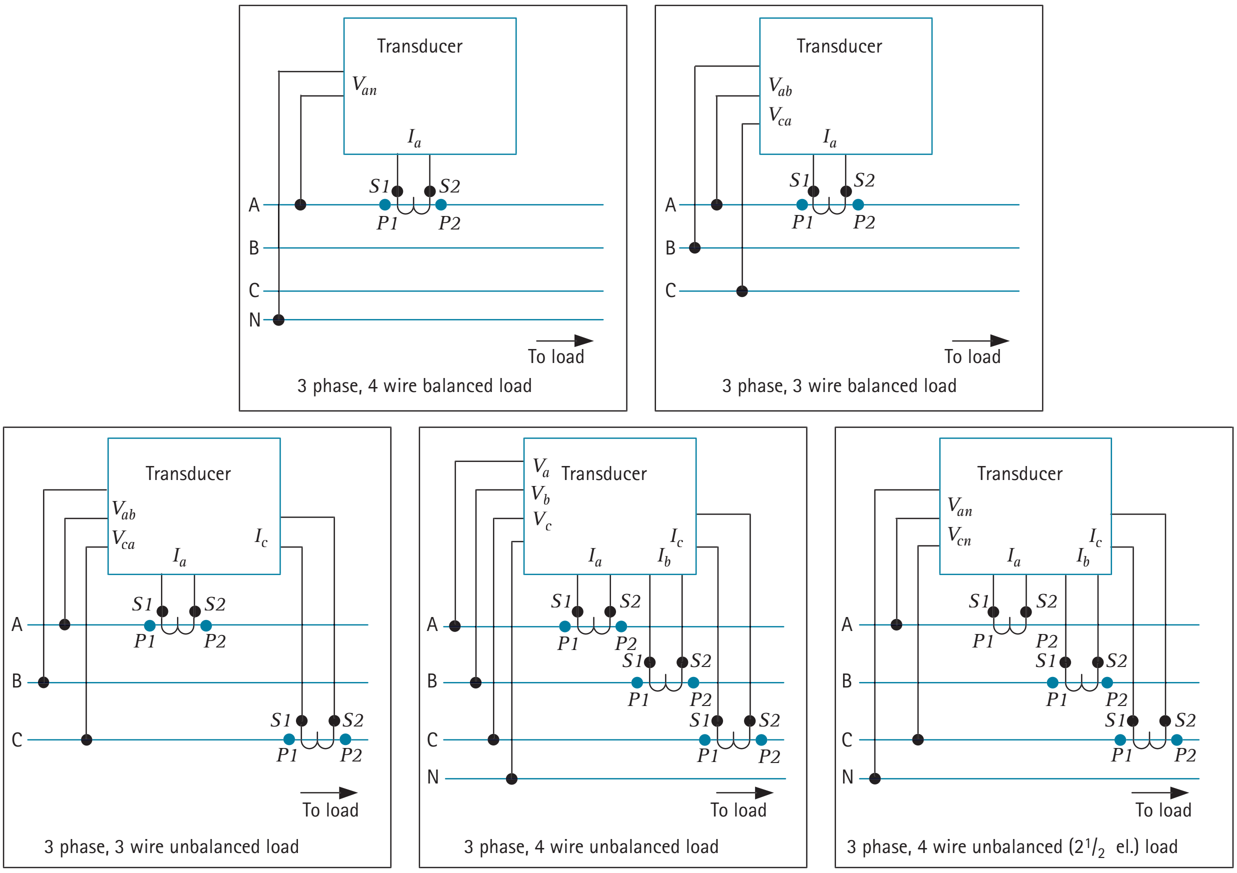


Figure 22.2: Connections for 3-phase watt/var transducers

22.5.6 Scaling

The relationship of the output current to the value of the measurand is of vital importance and needs careful consideration. Any receiving equipment must, of course, be used within its rating but, if possible, some kind of standard should be established.

As an example, examine the measurement of a.c. voltage. The primary system has a nominal value of 11kV and the transformer has a ratio of 11kV/110V. To specify the conversion coefficient for a 0-10mA voltage transducer to be 110V/10mA would not necessarily be the optimum. One of the objectives must be to have the capability of monitoring the voltage over a range of values so an upper limit must be selected – for instance +20%, or 132V. Using the original conversion coefficient, the maximum output of the transducer is required to be 12mA. This is within the capability of most 0-10mA transducers, the majority of which can accommodate an over-range of 25%, but it does mean any associated analogue indicating instrument must have a sensitivity of 12mA. However, the scale required on this instrument is now 0-13.2kV, which may lead to difficulty in drawing the scale in such a way as to make it readable (and conforms to the relevant standard). In this example, it would be more straightforward to establish the full-scale indication as 15kV and to make this equivalent to 10mA, thus making the specification of the display instrument much easier. The transducer will have to be specified such that an input of 0-150V gives an output of 0-10mA. In the case of transducers with a 4-20mA output, great care is required in the output scaling, as there is no over-range capability. The 20mA output limit is a fixed one from a measurement point of view. Such outputs are typically used as inputs to SCADA systems, and the SCADA system is normally programmed to assume that a current magnitude in excess of 20mA represents a transducer failure. Thus, using the above example, the output might be scaled so that 20mA represents 132V and hence the nominal 110V input results in an output of 16.67mA. A more convenient scaling might be to use 16mA as representing110V, with 20mA output being equal to 137.5V (i.e. 25% over-range instead of the 20% required). It would be incorrect to scale the transducer so that 110V input was represented by 20mA output, as the over-range capability required would not be available.

Similar considerations apply to current transducers and, with added complexity, to watt transducers, where the ratios of both the voltage and the current transformers must be taken into account. In this instance, the output will be related to the primary power of the system. It should be noted that the input current corresponding to full-scale output may not be exactly equal to the secondary rating of the current transformer but this does not matter - the manufacturer will take this into account.

Some of these difficulties do not need to be considered if the transducer is only feeding, for example, a SCADA outstation. Any receiving equipment that can be programmed to apply a scaling factor to each individual input can accommodate most input signal ranges. The main consideration will be to ensure that the transducer is capable of providing a signal right up to the full-scale value of the input, that is, it does not saturate at the highest expected value of the measurand.

22.5.7 Auxiliary Supplies

Many transducers do not require any auxiliary supply. These are termed 'self-powered' transducers. Of those that do need a separate supply, the majority have a biased, or live zero output, such as 4-20mA. This is because a non-zero output cannot be obtained for zero input unless a separate supply is available. Transducers that require an auxiliary supply are generally provided with a separate pair of terminals for the auxiliary circuit so that the user has the flexibility of connecting the auxiliary supply input to the measured voltage, or to a separate supply. However, some manufacturers have standardised their designs such that they appear to be of the self-powered type, but the auxiliary supply connection is actually internal. For a.c. measuring transducers, the use of a d.c. auxiliary supply enables the transducer to be operated over a wider range of input.

The range of auxiliary supply voltage over which a transducer can be operated is specified by the manufacturer. If the auxiliary voltage is derived from an input quantity, the range of measurement will be restricted to about ±20% of the nominal auxiliary supply voltage. This can give rise to problems when attempting to measure low values of the input quantity.

22.6 MEASUREMENT CENTRES

A Measurement Centre is effectively a collection of discrete transducers mounted in a common case. This is largely impractical if analogue technology for signal processing is used, but no such limitation exists if digital or numerical technology is adopted. Therefore, Measurement Centres are generally only found implemented using these technologies. As has been already noted in Chapter 7, a numerical relay can provide many measurements of power system quantities. Therefore, an alternative way of looking at a Measurement Centre that uses numerical technology is that it is a numerical relay, stripped of its protection functions and incorporating a wide range of power system parameter measurements.

This is rather an oversimplification of the true situation, as there are some important differences. A protection relay has to provide the primary function of protection over a very large range of input values; from perhaps 5% to 500% or greater of rated values. The accuracy of measurement, whilst important, is not required to be as accurate as, for instance, metering for tariff purposes. Metering does not have to cover quite such a wide range of input values, and therefore the accuracy of measurement is often required to be higher than for a protection relay. Additional functionality over that provided by the measurement functions of a protection relay is often required – for a typical set of functions provided by a measurement centre, see Table 22.3.

On the other hand, the fundamental measurement process in a measurement centre based on numerical technology is identical to that of a numerical relay, so need not be repeated here. The only differences are the ranges of the input quantities and the functionality. The former is dealt with by suitable design of the input signal conditioning and A/D conversion, the latter is dealt with by the software provided.

R.M.S. line currents	R.M.S. line voltages
Neutral current	R.M.S. phase voltages
Average current	Average voltage
Negative sequence voltage	Negative sequence current
Power (each phase and total)	Reactive Power (each phase and total)
Apparent Power (each phase and total)	Power factor (each phase and total)
Phase angle (voltage/current) – each phase	Demand time period
Demand current in period	Demand power in period
Demand reactive power in period	Demand VA in period
Demand power factor in period	Maximum demand current (each phase and total) since reset
Maximum demand (W and var) since reset	Energy, Wh
Energy, varh	Frequency
Individual harmonics (to 31st)	%THD (voltage) – each phase and total
%THD (current) – each phase and total	Programmable multiple analogue outputs

Table 22.3: Typical function set provided by a Measurement Centre

The advantages of a Measurement Centre are that a comprehensive set of functions are provided in a single item of equipment, taking up very little extra space compared to a discrete transducer for a much smaller number of parameters. Therefore, when the requisite CT's and VT's are available, it may well make sense to use a Measurement Centre even if not all of the functionality is immediately required. History shows that more and more data is required as time passes, and incorporation of full functionality at the outset may make sense. Figure 22.3 illustrates the wide variety of transducers and Measurement Centres available.

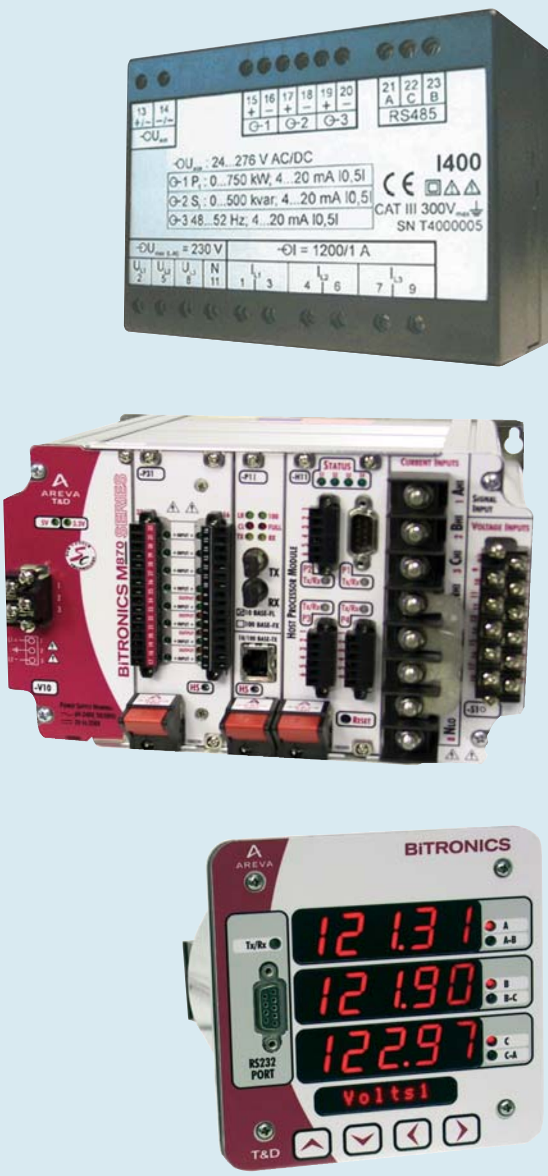


Figure 22.3: Typical transducers/Measurement Centres

22.7 TARIFF METERING

Tariff metering is a specialised form of measurement, being concerned with the measurement of electrical power, reactive power or energy for the purposes of charging the consumer. As such, it must conform to the appropriate national standards for such matters. Primary tariff metering is used for customer billing purposes, and may involve a measurement accuracy of 0.2% of reading, even for readings that are 5% or less of the nominal rated value. Secondary tariff metering is applied where the user wishes to include his own metering as a check on the primary tariff metering installed by the supplier, or within a large plant or building to gain an accurate picture of the consumption of energy in different areas, perhaps for the purpose of energy audits or internal cost allocation. The accuracy of such metering is rather less, an overall accuracy of 0.5% over a wide measurement range being typically required. As this is the overall accuracy required, each element in the metering chain (starting with the CT's/VT's) must have an accuracy rather better than this. Careful attention to wiring and mounting of the transducer is required to avoid errors due to interference, and the accuracy may need to be maintained over a fairly wide frequency range. Thus a tariff metering scheme requires careful design of all of the equipment included in the scheme. Facilities are normally included to provide measurements over a large number of defined time periods (e.g. 24 half-hour periods for generator energy tariff metering) so that the exporter of the energy can produce an overall invoice for the user according to the correct rates for each tariff period. The time intervals that these periods cover may change according to the time of year (winter, spring, etc.) and therefore flexibility of programming of the energy metering is required. Remote communications are invariably required, so that the data is transferred to the relevant department on a regular basis for invoicing purposes.

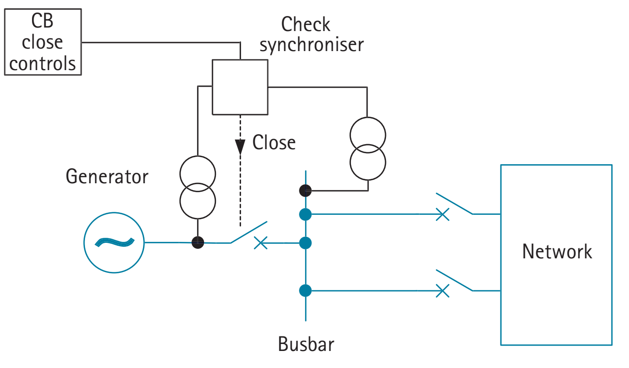
22.8 SYNCHRONISERS

Synchronisers are required at points on a power system where two supplies (either generator and grid, or two grid supplies) may need to be paralleled. They are more than just a measuring device, as they will provide contact closures to permit circuit breaker closing when conditions for paralleling (synchronising) are within limits. However, they are not regarded as protection relays, and so are included in this Chapter for convenience. There are two types of synchronisers - auto-synchronisers and check synchronisers.

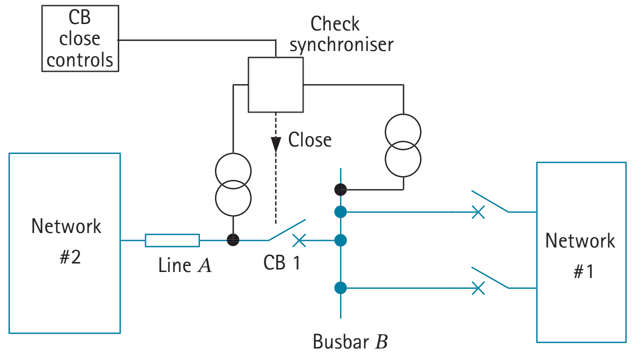
22.8.1 Check Synchronisers

The function of a check synchroniser is to determine if two voltages are in synchronism, or nearly so, and provide outputs under these conditions. The outputs are normally in the form of volt-free contacts, so that they may be used in CB control circuits to permit or block CB closing. When applied to a power system, the check synchroniser is used to check that it is safe to close a CB to connect two independent networks together, or a generator to a network, as in Figure 22.4. In this way, the check synchroniser performs a vital function in blocking CB closure when required.

Synchronism occurs when two a.c. voltages are of the same frequency and magnitude, and have zero phase difference. The check synchroniser, when active, monitors these quantities and enables CB close circuits when the differences are within pre-set limits. While CB closure at the instant of perfect synchronism is the ideal, this is very difficult to obtain in practice and some mismatch in one or more of the monitored quantities can be tolerated without leading to excessive current/voltage transients on CB closure. The check synchroniser has programmable error limits to define the limits of acceptability when making the comparison.



(a) Application to generator



(b) Application to two networks

Figure 22.4: Check synchroniser applications

The conditions under which a check synchroniser is required to provide an output are varied. Consider the situation of a check synchroniser being used as a permissive device in the closing control circuit of a CB that couples two networks together at a substation – Figure 22.4(b). It is not sufficient to assume that both networks will be live, situations where either Line A or Busbar B may be dead may have to be considered, leading to the functionality shown in Table 22.4(a).

Live bus/live line synchronising	Live bus/dead line synchronising
Dead bus/live line synchronising	Network supply voltage #1 deviation from nominal
Network supply voltage #2 deviation from nominal	Voltage difference within limits
Frequency difference within limits	Phase angle difference within limits
CB closing advance time	CB closing pulse time
Maximum number of synchronising attempts	

(a): Check synchroniser functionality

Incoming supply frequency deviation from nominal	Incoming supply voltage signal raise/lower
Incoming supply voltage raise/lower mode (pulse/continuous)	Incoming supply frequency raise/lower mode (pulse/continuous)
Incoming supply voltage setpoint	Incoming supply frequency setpoint
Voltage raise/lower pulse time	Frequency raise/lower pulse time

(b) Additional functions for auto-synchroniser

Table 22.4: Synchroniser function set

When the close signal is permitted, it may be given only for a limited period of time, to minimise the chances of a CB close signal remaining after the conditions have moved outside of limits. Similarly, circuits may also be provided to block closure if the CB close signal from the CB close controls is present prior to satisfactory conditions being present – this ensures that an operator must be monitoring the synchronising displays and only initiating closure when synchronising conditions are correct, and also detects synchronising switch contacts that have become welded together.

A check synchroniser does not initiate any adjustments if synchronising conditions are not correct, and therefore acts only as a permissive control in the overall CB closing circuit to provide a check that conditions are satisfactory. In a substation, check-synchronisers may be applied individually to all required CB's. Alternatively, a reduced number may be installed, together with suitable switching arrangements in the signal input/output circuits so that a single device may be selected to cover several CB's.

22.8.2 Auto-synchroniser

An auto-synchroniser contains additional functionality compared to a check synchroniser. When an auto-synchroniser is placed in service, it measures the frequency and magnitude of the voltages on both sides of the circuit breaker, and automatically adjusts one of the voltages if conditions are not correct. Application of auto-synchronisers is normally restricted to generators – i.e. the situation shown in Figure 22.4(a), replacing the check synchroniser with an auto-synchroniser. This is because it is generally not possible to adjust either of the network voltages by changing the settings of one or a very few equipments in a network. When applied to a generator, it is relatively easy to adjust the frequency and magnitude of the generated voltage by transmitting signals to the Governor and AVR respectively.

The auto-synchroniser will check the voltage of the incoming generator against the network voltage for compliance with the following (Table 22.4(a), (b)):

a. slip frequency within limits (i.e. difference in frequency between the generator and network)

b. phase difference between the voltages within limits

c. voltage magnitude difference within limits

The CB close command is issued automatically when all three conditions are satisfied. Checks may also be made that the network frequency and voltage is within pre-set limits, and if not the synchronising sequence is locked out. This prevents synchronising under unusual network conditions, when it may not be desirable. This facility should be used with caution, since under some emergency conditions, it could block the synchronising of a generator that was urgently required in service to help assist in overcoming the condition.

If (a) above is not within limits, signals are sent automatically to the governor of the generating set to adjust the speed setpoint appropriately. In the case of (c) not in limits, similar signals are sent to the Automatic Voltage Regulator to raise or lower the setpoint. The signals are commonly in the form of pulses to raise or lower the setpoint, but could be continuous signals if that is what the particular equipment requires. It is normal for the speed and voltage of the generator to be slightly higher than that of the network, and this can be accommodated either by initial settings on the Governor/AVR or by providing setpoint values in the synchroniser. This ensures stable synchronising and export of power at lagging power factor to the network by the generator after CB closure. The possibility of tripping due to reverse/low forward power conditions and/or field failure/under-excitation is avoided. Use of an auto-synchroniser also helps avoid human error if manual synchronising were employed – there is potential for damage to equipment, primarily the generator, if synchronising outside of permitted limits occurs.

To ensure that the CB is closed at the correct instant, the CB close time is normally a required data item. The auto-synchroniser calculates from a knowledge of this and the slip frequency the correct time in advance of phase co-incidence to issue the CB close command. This ensures that the CB closes as close to the instant of phase co-incidence as possible. Upon receipt of the signal indicating 'CB closed' a further signal to raise frequency may be sent to the governor to ensure stable export of power is achieved. Conversely, failure of the CB to close within a set time period will reset the auto-synchroniser, ready for another attempt, and if further attempts are still unsuccessful, the auto-synchroniser will lock out and raise an alarm.

Practice in respect of fitting of auto-synchronisers varies widely between Utilities. Where policy is flexible, it is most common when the time to synchronise is important – i.e. emergency standby and peak lopping sets. Many Utilities still relay on manual synchronising procedures. It is also possible for both an auto-synchroniser and check-synchroniser to be fitted in series. This provides protection against internal failure of the auto-synchroniser leading to a CB close command being given incorrectly.

22.9 DISTURBANCE RECORDERS

Power systems suffer from various types of disturbances. In post-fault analysis, it is beneficial to have a detailed record of a disturbance to enable the initiating event to be distinguished from the subsequent effects. Especially where the disturbance causes further problems (e.g.

single-phase fault develops into 3-phase), a detailed recording of the fault may be required to distinguish between cause and effect. If the effects of a fault are spread over a wide area, records of the disturbance from a number of locations can assist in determining the location of the disturbance. The equipment used for this purpose is known as a disturbance, or fault, recorder.

22.9.1 Disturbance Recorder Features

A disturbance recorder will normally have the following capabilities:

a. multi-channel analogue input waveform recording

b. multi-channel digital input recording

c. storage of several fault records, ready for download/analysis

d. recording time of several seconds per disturbance

e. triggering from any analogue or digital input channel, or quantity derived from a combination of inputs, or manually

f. distance to fault location for one or more feeders

g. variable pre/post trigger recording length

h. time synchronisation (IRIG-B, GPS, etc.)

i. programmable sampling rates

j. standard data transfer formats (IEEE COMTRADE (now IEC 60255-24), etc.

k. communication links to control centre, etc. (Ethernet, modem, etc.)

l. self-monitoring/diagnostics

Analogue channels are provided to record the important currents and voltages at the fault recorder location. High resolution is required to ensure accurate capture of the waveforms, with 14 or 16 bit A/D conversion being usual. Digital inputs are provided to capture signals such as CB opening, protection relay operation, intertrip signals, etc. so that a complete picture of the sequence of events can be built up. The information can then be used to check that the sequence of operations post-fault is correct, or assist in determining the cause of an unexpected sequence of operations. To avoid loss of the disturbance data, sufficient memory is provided to capture and store the data from several faults prior to transfer of the data for analysis. Flexibility in the triggering arrangements is extremely important, as it is pointless to install a disturbance recorder, only for it to miss recording events due to lack of appropriate triggering facilities. It is normal for triggering to be available if the relevant threshold is crossed on any analogue or digital channel, or a quantity that can be derived from a combination of inputs.

Power system disturbances may last from periods of a few seconds to several minutes. To ensure that maximum benefit is obtained from the investment, a disturbance recorder must be able to capture events over a wide range of timescales. This leads to the provision of programmable sampling rates, to ensure that short-term transients are captured with sufficient resolution while also ensuring that longer-term ones have sufficient of the transient captured to enable a meaningful analysis to be undertaken. The record for each disturbance is divided into sections covering pre-fault, fault, and post–fault periods, and each of these periods may have different sampling rates. Time synchronisation is also a vital feature, to enable a recording from one recorder to be aligned with another of the same event from a different recorder to obtain a complete picture of events.

Since most distrubance recorders are fitted in substations that are normally unmanned, the provision to download captured information is essential. Each fault recording will contain a large amount of data, and it is vital that the data is uniquely identified in respect of recorder, fault event, channel, etc. Standards exist in field to facilitate the interchange of data, of which perhaps the best known is the IEEE COMTRADE format, now also an IEC standard. Once downloaded, the data from a disturbance recorder can be analysed by various software packages, such as WinAnalyse, Eview, or TOP2000. The software will often have the ability to calculate the fault location (distance-to-fault), superimpose waveforms to assist in fault analysis, and perform harmonic and other analyses.