Electrical Instrumentation

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Lecture Outline

- Introduction
- Principle of measurement
- Performance Characteristics
- Static Characteristics
- Error in Measurement
- Types of Error
- Sources of Error

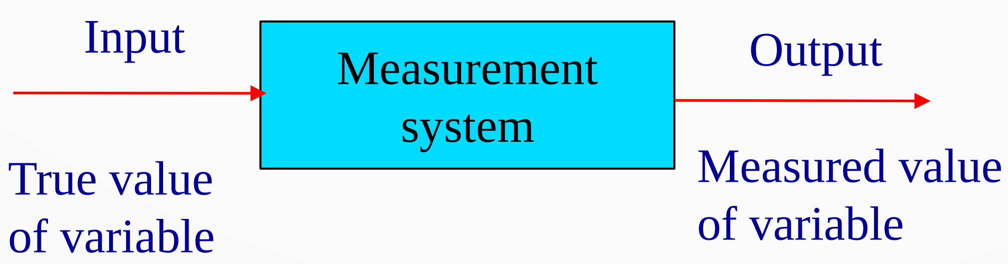
Introduction

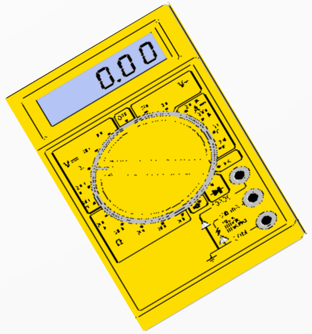
- Instrumentation is a technology which serves not only science but all branches of engineering, medicine, and almost every human endeavor.
- A parameters in-dept knowledge largely depends, and can easily be understood by the use of measurement.
- Measuring – It is used to monitor a process or operation, or as well as the controlling process.
- For example; to indicate environmental condition, we used *thermometers*, *barometers*, *anemometers*, etc. Others includes; multimeter, electrical meters etc.

Principle of measurement

The intelligent selection and use of measuring equipment depends on a broad knowledge of what is available and how the performance of the equipment renders itself for the job to be performed.

A process to present an observer with a numerical value corresponding to the variable being measured by using appropriate instrument.





Principle of measurements

- The major problem encountered with any measuring instrument is the error.

- Therefore, it is necessary to select the appropriate measuring instrument & measurement method which minimises error

- To avoid errors in any experimental work, careful planning, execution & evaluation of the experiment are essential

Principle of measurements

Before measurement process, we have to ensure:

- Methods/procedures of measurement
- Characteristics of the parameter
- Quality: time and cost, instrument capabilities, knowledge of measurement, acceptable result
- What instrument to use.

Principle of measurements

During the measurements we have to ensure:

- Quality- best instrument chosen, suitable position when taking the data, etc.
- Safety- electric shock, overloaded, instrument limits, read instruction manual
- Sampling – observe parameter changing, taking enough sample

After measurement

Analyse the data mathematically/statistically.

Full result must be reported completely and accurately

Performance Characteristics

Knowing the performance characteristics of an instrument is essential for selecting the most suitable instrument for specific measuring jobs. It consist of two basic characteristics, which are;

Static and Dynamic

Static Characteristics

To measure unvarying process conditions, the static characteristics of the instrument is used.

All the static performance characteristics are obtained by one form or another by a process called calibration.

There are a number of related definitions or characteristics, these are described as follows.

Instrument: A device or mechanism used to determine the present value of the quantity under measurement.

Static Characteristics

Measurement: The process of determining the amount, degree, or capacity by comparison(direct or indirect) with the accepted standards of the systems units being used.

Accuracy: The degree of exactness (closeness) of a measurement compared to the expected (desired) value.

Resolution: The smallest change in a measured variable to which an instrument will respond.

Precision: A measure of the consistency or repeatability of measurements, that is successive reading do not differ. (Precision is the consistency of the instrument output for a given value input.)

Static Characteristics

Expected value: The design value, that is the most probable value that calculations indicate one should expect to measure.

Error: The deviation of the true value from the desired value.

Sensitivity; The ration of the change in output (response) of the instrument to a change of input or measured variable

Error in measurement

Measurement is the process of comparing an unknown quantity with an accepted standard quantity.

The measurement obtained is quantitative measure of the so-called "true value" since it is very difficult to define the true value, the term "expected value " is used.

Any measurement is affected by many variables, hence the results rarely reflect the expected value.

Some factors that affect the measurement are related to the measuring instruments.

Error in measurement

Definition

Error is defined as the difference between the measured value and the expected value (true value) of the measured parameter.

Error may be expressed as absolute or as percentage of error.

Expressing error as Absolute

Absolute error may be defined as the ***difference*** between the ***expected value*** of the variable and the *measured value* of the variable, or …

Error in measurement

Or Absolute error mathematically is stated as

$$e = Y_n - X_n$$

where:

e = absolute error

Y_n = expected value

X_n = measured value

Error in measurement

Expressing error as Percentage

To express error in percentage

$$\%\ \text{error} = \frac{e}{Y_n}(100) \quad , e = Y_n - X_n$$

We also derived relative accuracy, A;

$$A = 1 - \left| \frac{Y_n - X_n}{Y_n} \right|$$

Where A is relative accuracy

Accuracy is expressed as % accuracy

***a* = 100% - % error**

or

***a* = A x 100%**

Error in measurement

Example 1: The expected value of the voltage across a resistor is 90 V. However, measurement yields a value of 69 V. Calculate:

a) absolute error
b) % error
c) relative accuracy
d) % accuracy

Solution

a. Absolute error $e = Y_n - X_n = 90 - 89 = 1$ V

b. $\% \text{ Error } = \frac{Y_n - X_n}{Y_n} x \ 100 = \frac{90-89}{90} x \ 100 = 1.11\%$

c. *Relative Accuracy*

$$A = 1 - \left|\frac{Y_n - X_n}{Y_n}\right| = A = 1 - \left|\frac{90-89}{90}\right| = 1 - \frac{1}{90} = \frac{89}{90} = 0.9889$$

Error in measurement

Example 1 cont...

d. % Accuracy

$$a = 100\% - \%\ \text{error} = 100\% - 1.11\% = 98.89\%$$

$$\text{or}\quad a = A \times 100\% = 0.9889 \times 100\% = 98.89\%$$

If a measurement is accurate, it must be precise, that is. Accuracy means precision. However a precision measurement may not be accurate.

The precision of a measurement is quantitative or numerical indication of the closeness with which a repeated set of measurement of the same variable agree with the average set of measurement. Precision can be expressed mathematically as .....

Error in measurement

$$\boldsymbol{Precision = 1 - \left|\frac{X_n - \overline{X}_n}{\overline{X}_n}\right|}$$

where

X_n = the value of the n^{th} measurement

$\overline{X}_n$ = the average of the set of n measurements

= sum of the n^{th} measurement values / n^{th}

Error in measurement

Measurement number	Measurement value *Xn*
1	98
2	101
3	102
4	97
5	101
6	100
7	103
8	98
9	106
10	99

The following set of 10 measurement that were recorded in the laboratory. Calculate the precision of the 6th measurement.

$\overline{X}_n$ = ??

Precision = ??

$$\overline{X}_n = \frac{Sum\ of\ the\ 10\ measurement\ values}{10} = \frac{1005}{10} = 100.5$$

For the 6th reading

$$Precision = 1 - \left|\frac{X_n - \overline{X}_n}{\overline{X}_n}\right| = 1 - \left|\frac{100 - 100.5}{100.5}\right| = 1 - \frac{0.5}{100.5} = \frac{100}{100.5} = 0.995$$

Types of Error

NB: The accuracy and precision of measurement depend not only on the quality of the measuring instrument but also on the person using it.

Types of Error in measurement

Static Error

The static error of a measuring instrument is the numerical difference between the true value of a quantity and its value as obtained by measurement. (i.e. repeated measurement of the same quantity gives different indications.) Static errors are categorized as

- Gross errors or human error
- Systematic errors and
- Random errors

Gross or Human Error

- These are errors due to human mistakes in reading or in using instruments or errors in reading observations

- Example: incorrect reading, incorrect recording, improper use of instruments, etc.

- To minimize:

  - take at least 3 separate reading
  - take proper care in reading & recording

Systematic Error

These errors occur due to instrument's problem or environmental effects or observational errors. A constant uniform deviation of the operation of an instrument is known as systematic error.

Examples

- defective or worn parts
- ageing
- parallax error
- wrong estimation reading scale

There are basically three types of systematic errors

- Instrumental errors
- Environmental errors
- Observational errors

Systematic Error - types

Instrumental errors :

Due to friction in the bearings of the meter movement, incorrect spring tension, improper calibration, or faulty instruments

- can be reduced by proper maintenance, use, and handling of instruments

Environmental errors :

Due to external condition of the measuring

Eg: effects of change in temperature, humidity, barometric pressure, electrostatic fields etc.

- can be avoided by: air conditioning, hermetically sealing certain components in the instrument and using magnetic shields

Observational errors :

Errors that introduced by the observer. The two most common observational errors are probably the parallax error introduced in reading a meter scale and the error of estimation when obtaining a reading from a meter scale

Gross or Human Error

Example 2: A voltameter having a sensitivity of 1kΩ/V is connected across an unknown resistance in series with a milliammeter reading 80V on 150 V scale. When the milliammeter reads 10mA, Calculate the;

i. Apparent resistance od the unknown resistance
ii. Actual =l resistance of the unknown resistance
iii. Error due to the loading effect of the voltmeter

Solution

i. The total circuit resistance $R_t = \frac{V_T}{I_T} = \frac{80}{10mA} = 8k\Omega$

(Neglecting the resistance of the milliammeter)

ii. The voltameter resistance equals R_v =1000Ω/V x 150 = 150kΩ

$$actual\ value\ of\ u\ nknown\ resistance\ R_x = \frac{R_T\ x\ R_v}{R_v\ \ - R_T} = \frac{8k\ x\ 150k}{150k\ \ - 8k} = 8.45k$$

Gross or Human Error

Example 2 Cont.......

iii. % error = $\frac{Actual\ value\ -Apparent\ value}{Actual\ value}$

$$= \frac{8.45k - 8k}{8.45k} \text{ x } 100 = 0.053 \text{ x } 100 = 5.3\%$$

Random Errors

These errors remain after gross and systematic errors have been substantially reduced.

They are generally the accumulation of a large number of small effects
May be of real concern only in measurements requiring a high degree of accuracy.

Such errors can only be analyzed statistically and can be treated mathematically.

Limiting Errors

Most manufacturers of instruments state that an instrument is accurate within a certain percentage of a full-scale reading

Eg: A voltmeter is accurate within ±*2% at full-scale deflection (*limiting errors)

However, with reading less than full-scale, the limiting error will increase, therefore, it is important to obtain measurements as close as possible to full scale

Limiting Errors

Example 3: A 300-V voltmeter is specified to be accurate within ±2% at full scale. Calculate the limiting error when the instrument is used to measure a 120-V source?

Solution

The magnitude of the limiting error is:

$2/100 \times 300 = 6V$

Therefore, the limiting error at 120 V is:

$6/120 \times 100 = 5\%$

(reading < full scale, limiting error increased)

Sources of Errors

The sources of error, other than inability of piece of hardware to provide true measurement, are as follows.

- Insufficient knowledge of process parameters and design conditions
- Poor design.
- Change in process parameters, irregularities, upsets, etc.
- Poor maintenance.
- Errors caused by person operating the instrument or equipment.
- Certain design limitations.