
ELECTRICAL AND ELECTRONIC MEASUREMENTS

Chapter 4

MEASUREMENT OF ELECTRIC ENERGY

- 4.1 Single phase and three phase electronic energy meter
- 4.2 Single phase and three phase induction type energy meter
- 4.3 Calibration of single-phase electronic energy meter using direct loading

Study Notes for Engineering Students

Detailed Notes • Diagrams • Tables • 15 MCQs with Answer Key •
10 Broad Questions

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Chapter 4: Measurement of Electric Energy

Introduction

Electrical energy is the total amount of work done by an electric current over a period of time. Electricity supply companies sell energy, not power, so every consumer connection needs an instrument that continuously measures and records the energy used. This instrument is called an **energy meter** (also called a watt-hour meter or kilowatt-hour meter). Energy is the product of power and time:

$$\text{Energy (E)} = \text{Power (P)} \times \text{Time (t)} = V I \cos \phi \times t$$

The SI unit of energy is the joule, but the commercial (billing) unit is the **kilowatt-hour (kWh)**, popularly called one **unit** of electricity.

$$1 \text{ kWh} = 1000 \text{ W} \times 3600 \text{ s} = 3.6 \times 10^6 \text{ J}$$

An energy meter is an **integrating instrument**: it adds up (integrates) the instantaneous power over time. This is the main difference from a wattmeter, which is an *indicating* instrument that shows only the instantaneous power.

Point	Wattmeter	Energy meter
Quantity measured	Instantaneous (average) power in watts	Total energy in kWh over a period
Type of instrument	Indicating instrument	Integrating instrument
Reading	Pointer deflection on a scale	Dial / digital register that keeps increasing
Use	Laboratory, power checking	Billing of consumers, energy auditing

Classification of Energy Meters

Energy meters used on AC supply are mainly classified as follows:

Type	Principle	Remarks
Induction (electromechanical) type	Interaction of eddy currents in an aluminium disc with alternating magnetic fluxes	Used for AC only; being replaced by electronic meters
Electronic (static) type	Electronic multiplication of voltage and current signals; digital counting of energy pulses	No moving parts; high accuracy; supports smart features
Hybrid type	Electronic measurement with an electromechanical register	Transitional design

By supply system, meters are also divided into **single-phase** meters (domestic and small loads) and **three-phase** meters (industrial and commercial loads, available in 3-wire and 4-wire forms).

Important terms used with energy meters

- **Basic current (I_b):** the current value on which the performance of a direct-connected meter is based.
- **Maximum current (I_{max}):** the highest current at which the meter meets its accuracy requirement.
- **Meter constant (K):** the number of revolutions of the disc (induction meter) or impulses (electronic meter) per kWh.
- **Accuracy class:** the class index (such as 1.0 or 2.0) that gives the permitted percentage error limits.
- **Starting current:** the smallest current at which the meter starts to register continuously.
- **Creep (no-load running):** continuous registration of the meter when voltage is applied but no load current flows.
- **Calibration:** comparing the meter with a more accurate reference standard and adjusting it so that the error stays within limits.

4.1 Single Phase and Three Phase Electronic Energy Meter

4.1.1 Introduction

An electronic (static) energy meter measures energy using electronic circuits instead of a rotating disc. Voltage and current are sensed, converted to digital form, multiplied to obtain power, and the result is accumulated as energy. Since there are no moving parts, friction, creep from vibration and wear are absent, and the meter keeps its accuracy over a wide range of load, power factor and temperature.

Advantages over induction type meters

- High accuracy over a wide range of load and power factor (class 1.0, 0.5S, 0.2S are possible).
- No moving parts, so no friction error, no wear and very long life.
- Very low self-consumption (burden).
- Not affected by mounting position or vibration.
- Can measure kWh, kVAh, kVARh, maximum demand, power factor and time-of-day (ToD) data.
- Tamper detection, event logging and remote reading (AMR / smart metering) are possible.
- Compact size and light weight.

4.1.2 Types of Electronic Energy Meters

Basis	Types
Number of phases	Single-phase two-wire; three-phase three-wire (two element); three-phase four-wire (three element)
Quantity measured	Active energy (kWh), apparent energy (kVAh), reactive energy (kVARh), maximum demand (kW / kVA)
Accuracy class	Class 1.0 and 2.0 (IS 13779); Class 0.5S and 0.2S for high-accuracy / HT metering (IS 14697)
Connection	Direct connected (up to about 100 A) and CT / PT operated meters
Features	Basic meter, ToD meter, prepaid meter, smart meter with communication

4.1.3 Constructional Features

A single-phase electronic energy meter is made of the following functional blocks (Fig. 4.1).

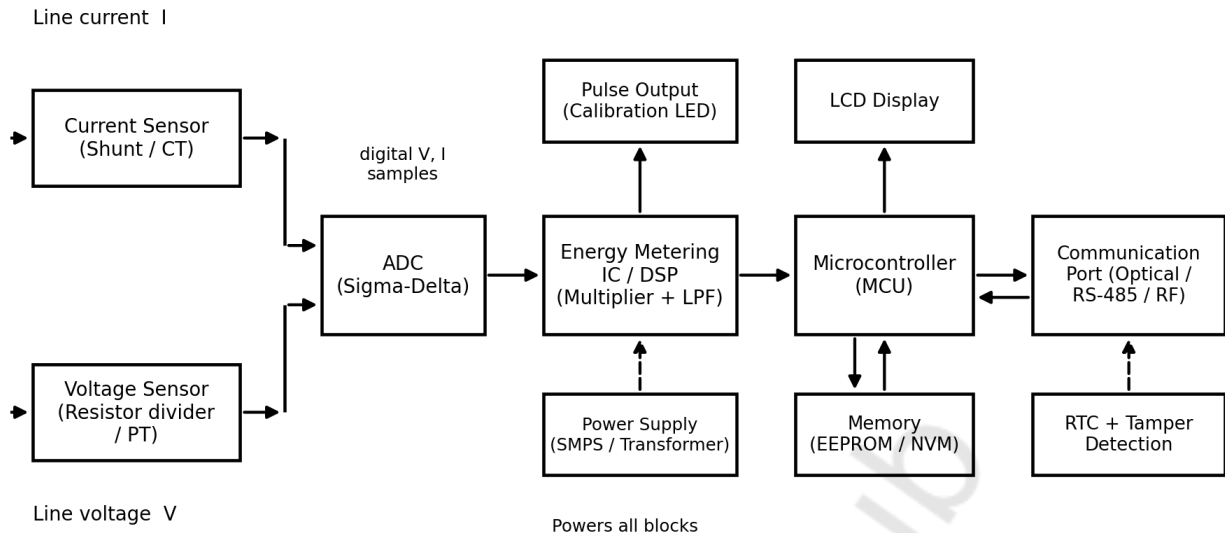


Fig. 4.1: Block diagram of a single-phase electronic energy meter

Block	Function
Current sensor	Converts the line current into a small voltage signal. A manganin shunt , a current transformer (CT) , a Hall-effect sensor or a Rogowski coil is used.
Voltage sensor	Reduces the line voltage to a safe level (a few hundred millivolts) with a resistor potential divider or a potential transformer (PT).
ADC	A sigma-delta analog-to-digital converter changes the sensed analog signals into digital samples; an anti-aliasing filter precedes it.
Energy metering IC / DSP	Multiplies voltage and current samples to get instantaneous power, filters it to get average power and produces an energy-proportional pulse output.
Microcontroller (MCU)	Accumulates energy in registers, controls display, memory and communication, and carries out calibration and tamper logic.
Display	A liquid crystal display (LCD) shows cumulative kWh and other parameters.
Memory	EEPROM / non-volatile memory stores energy readings, calibration constants and events even when the supply fails.
Calibration LED / pulse output	Blinks at a rate proportional to power (for example 3200 imp/kWh). It is used for testing and calibration.
Power supply	Capacitor-drop, transformer or SMPS type supply that powers the electronic circuits from the mains.
Communication port	Optical port, RS-485 or RF module for meter reading and data transfer.
RTC and tamper detection	Real-time clock for time-of-day billing; sensors detect magnetic interference, cover opening and neutral disturbance.

4.1.4 Working Principle

Let the supply voltage be $v = V_m \sin \omega t$ and the load current be $i = I_m \sin (\omega t - \phi)$. The instantaneous power is the product of the two:

$$p = v \times i = V I \cos \phi - V I \cos (2\omega t - \phi)$$

The first term is constant and equals the average (active) power. The second term oscillates at twice the supply frequency and averages to zero over a cycle. A low pass filter (or averaging in the digital domain) removes it, giving:

$$P = V I \cos \phi \text{ and } E = \int P dt$$

Steps in the working of the meter

1. The current sensor and voltage sensor produce signals proportional to load current and line voltage.
2. The ADC samples both signals many times in each cycle (a few thousand samples per second).
3. The DSP in the metering IC multiplies each pair of samples: $p[n] = v[n] \times i[n]$.
4. The products are averaged to give active power, $P = (1/N) \sum v[n] i[n]$.
5. The power value is converted into a pulse train whose frequency is proportional to power. Each pulse stands for a fixed amount of energy.
6. The MCU counts the pulses, adds them to the energy register, shows the total on the LCD and stores it in memory.

Meter constant and pulse relation

The meter constant K of an electronic meter is the number of impulses given out per kWh (imp/kWh). Then:

$$\text{Energy per pulse} = 1 / K \text{ kWh} = 1000 / K \text{ Wh}$$

$$\text{Pulse frequency (pulses per second)} = K \times P / (1000 \times 3600) \text{ (P in watts)}$$

Example 4.1: A meter has a constant of 3200 imp/kWh. Find the energy per pulse and the time between pulses for a 1 kW load.

Energy per pulse = $1000 / 3200 = 0.3125$ Wh. Pulses per hour at 1 kW = 3200. Time between pulses = $3600 / 3200 = 1.125$ s.

Single phase and three phase meters

A **single-phase** meter has one measuring element: one current sensor and one voltage sensor. A **three-phase** electronic meter has two or three such measuring elements whose power outputs are added inside the metering IC. By **Blondel's theorem**, a system of n wires needs $(n - 1)$ measuring elements, so a 3-wire system needs 2 elements and a 4-wire system needs 3 elements.

Point	Single-phase meter	Three-phase meter
Measuring elements	One	Two (3-phase 3-wire) or three (3-phase 4-wire)
Current sensors	One (shunt or CT)	Two or three (CTs, usually)
Voltage sensors	One divider	Two or three dividers / PTs
Total power	$P = V I \cos \phi$	$P = P_1 + P_2 (+ P_3)$ added electronically
Typical use	Homes, shops, small loads	Industries, commercial buildings, HT consumers
Extra features	Basic kWh registration	kVAh, kVARh, maximum demand, phase-wise voltage / current / power factor

4.1.5 Different Types of Errors and Their Compensation

Though electronic meters are very accurate, some errors arise from the sensors, the analog circuits and the digital processing. The percentage error of a meter is calculated as:

$$\% \text{ Error} = (\text{Energy recorded by meter} - \text{True energy}) / \text{True energy} \times 100$$

Type of error	Cause	Compensation
Offset error	DC offset in amplifiers and ADC adds a false component to the signal.	High pass filter / digital DC-removal in the metering IC; auto-zero circuits.
Gain error	Tolerance of shunt, divider resistors and reference voltage changes the scale factor.	Software calibration by adjusting the gain (calibration) register at rated load.
Phase error	Phase shift of the CT and mismatch of filters in the voltage and current channels. It is serious at low power factor.	Phase calibration by a small time delay (phase register) applied to one channel.
Non-linearity error	Non-linear behaviour of the sensors and ADC at very light or very heavy loads.	Multi-point calibration at different loads; use of good linear sensors; digital correction.

Type of error	Cause	Compensation
Temperature error	Drift of reference voltage, shunt resistance and crystal frequency with temperature.	Low temperature-coefficient components (manganin shunt, precision reference); on-chip temperature sensor with digital compensation.
Voltage and frequency variation error	Changes in supply voltage and frequency affect the sensing and filtering circuits.	Wide-range design and compensation algorithms; calibration at several voltages.
Harmonic / waveform error	Distorted currents (rectifier loads) and DC in the current can saturate a CT and cause wrong readings.	Use of shunt, Rogowski coil or DC-immune CT; high sampling rate and wide bandwidth.
Creep (no-load registration)	Noise and offset create small power values even when load current is zero.	Anti-creep (no-load threshold) in the IC: no pulses below a minimum power level.
Quantisation and rounding error	Finite resolution of the ADC and finite word length of the DSP.	High resolution (16 to 24-bit) sigma-delta ADC and oversampling.
Interference errors	External magnetic fields, EMI, ESD and surges disturb the sensors and circuits.	Shielding, filters, surge protection, magnetic-field tamper detection.
Clock (RTC) error	Crystal frequency drift upsets time-of-day billing.	Temperature-compensated crystal and periodic time synchronisation.

4.2 Induction Type Energy Meter (Single Phase and Three Phase)

4.2.1 Introduction

The induction type energy meter is an electromechanical meter that works on the same principle as an induction motor. It has been the most widely used energy meter for AC circuits because it is simple, rugged, cheap and has a long life. It works on AC supply only. Two alternating fluxes, one proportional to voltage and the other to current, act on an aluminium disc and produce a driving torque proportional to power. The disc rotates at a speed proportional to the power consumed, so the number of revolutions is proportional to the energy.

4.2.2 Constructional Features of Single Phase Induction Energy Meter

The meter has four main parts, as shown in Fig. 4.2.

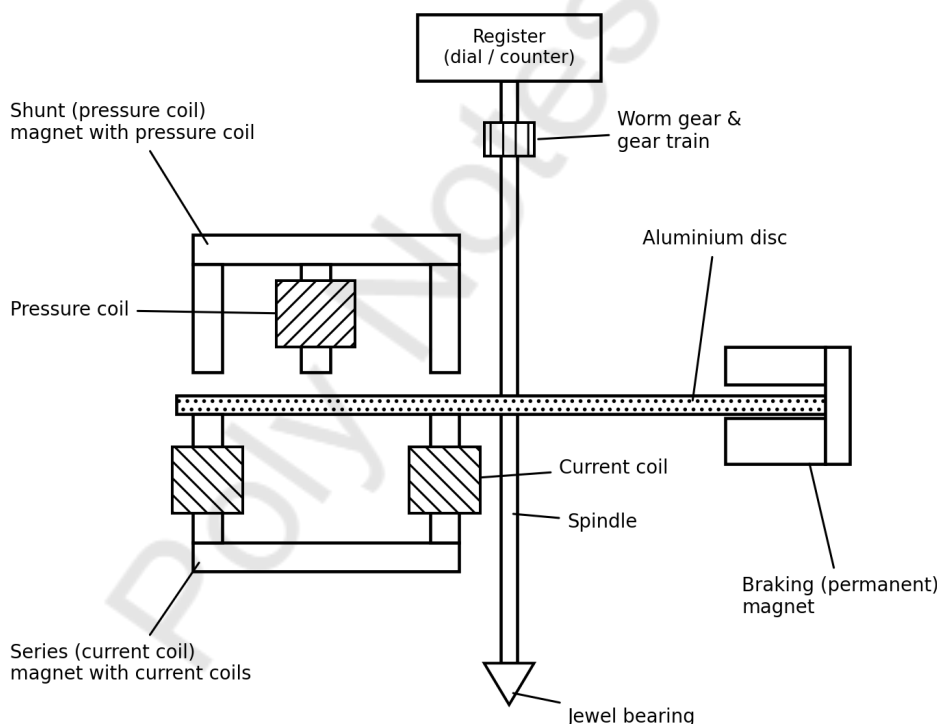


Fig. 4.2: Construction of a single-phase induction type energy meter

(a) Driving system

- **Shunt magnet (pressure coil magnet):** a laminated E-shaped or U-shaped core carrying the **pressure (potential) coil**. The coil has many turns of fine wire and is connected across the supply. It is highly inductive, so the flux it produces lags the supply voltage by nearly 90° .

- **Series magnet (current coil magnet):** a laminated U-shaped core carrying the **current coil**. The coil has a few turns of thick wire and is connected in series with the load. Its flux is proportional to the load current and in phase with it.
- **Lag adjustment device:** a copper shading band on the central limb of the shunt magnet (or a lag coil) that makes the shunt flux lag the voltage by exactly 90° .

(b) Moving system

- An **aluminium disc** mounted on a light spindle is placed in the air gap between the shunt and series magnets.
- The spindle rests on a **jewel bearing** at the bottom (many modern meters use magnetic suspension) and is guided by a bearing at the top, to keep friction very low.
- A **worm gear** on the spindle drives the registering mechanism.

(c) Braking system

- A **permanent (braking) magnet** is placed near the edge of the disc. When the disc rotates, eddy currents are produced in it and give a braking torque proportional to the speed.
- The position of the magnet can be changed to adjust the braking torque and hence the meter speed.

(d) Registering (counting) system

- A train of gears reduces the disc revolutions and moves the pointers of the dials (or the digits of a cyclometer register).
- The register is calibrated to read energy directly in kWh.

4.2.3 Working Principle

Consider the phasor diagram of Fig. 4.3. Let V be the supply voltage and I the load current, lagging V by the angle ϕ .

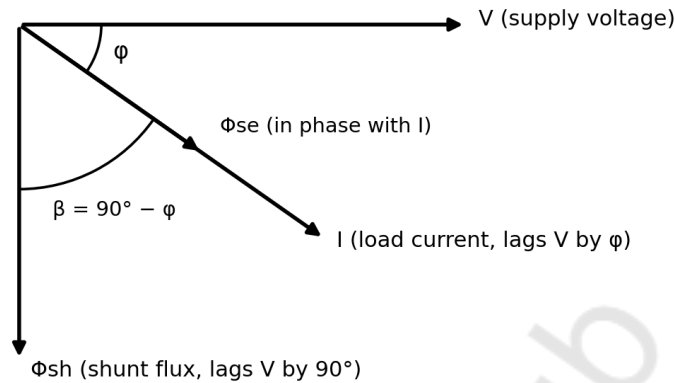


Fig. 4.3: Phasor diagram of the induction type energy meter

- The shunt flux Φ_{sh} is proportional to V and lags V by 90° .
- The series flux Φ_{se} is proportional to I and is in phase with I .
- The angle between the two fluxes is $\beta = 90^\circ - \phi$.
- The fluxes cut the aluminium disc and induce eddy currents in it. The interaction of each flux with the eddy currents of the other flux produces a driving torque.

Torque equation

The driving torque of an induction type instrument is proportional to the product of the two fluxes, the frequency and the sine of the phase angle between them:

$$T_d \propto \Phi_{sh} \Phi_{se} f \sin \beta$$

Substituting $\beta = 90^\circ - \phi$, $\Phi_{sh} \propto V$ and $\Phi_{se} \propto I$, and keeping the frequency constant:

$$T_d \propto V I \sin (90^\circ - \phi) = V I \cos \phi = P$$

The driving torque is therefore proportional to the active power. The braking torque produced by the permanent magnet is proportional to the speed N of the disc: $T_b \propto N$. At steady speed the driving and braking torques are equal:

$$T_d = T_b \Rightarrow N \propto P$$

Total revolutions in time $t = N \times t \propto P \times t = \text{Energy}$. Hence the number of revolutions of the disc is proportional to the energy consumed, and the register that counts the revolutions reads the energy.

$$\text{Energy recorded} = \text{Number of revolutions} / \text{Meter constant (rev per kWh)}$$

Example 4.2: A meter with constant 600 rev/kWh is connected to a 3 kW load for 2 hours. The disc makes 3500 revolutions. Find the percentage error.

True energy = $3 \times 2 = 6$ kWh. Energy recorded = $3500 / 600 = 5.833$ kWh. % Error = $(5.833 - 6) / 6 \times 100 = -2.78\%$ (the meter runs slow).

4.2.4 Three Phase Induction Type Energy Meter

A three-phase induction meter is made by combining two or three single-phase measuring elements on a common spindle, so that the torques of all elements add up. The registered energy is then the total energy of the three-phase load.

- **Two-element meter (3-phase 3-wire):** works like the two-wattmeter method. Two elements, each with its own series and shunt magnet, act on one disc or on two discs on a common spindle. Total torque $\propto P_1 + P_2$.
- **Three-element meter (3-phase 4-wire):** three elements, one in each phase, measure the phase powers with respect to neutral. Total torque $\propto P_1 + P_2 + P_3$ (Fig. 4.4).
- To avoid mutual interference between the elements, a separate disc for each element, magnetic screens or a suitable spacing is used.
- A **balancing adjustment** is provided so that each element develops equal torque for equal power. This makes the meter read correctly even with an unbalanced load.

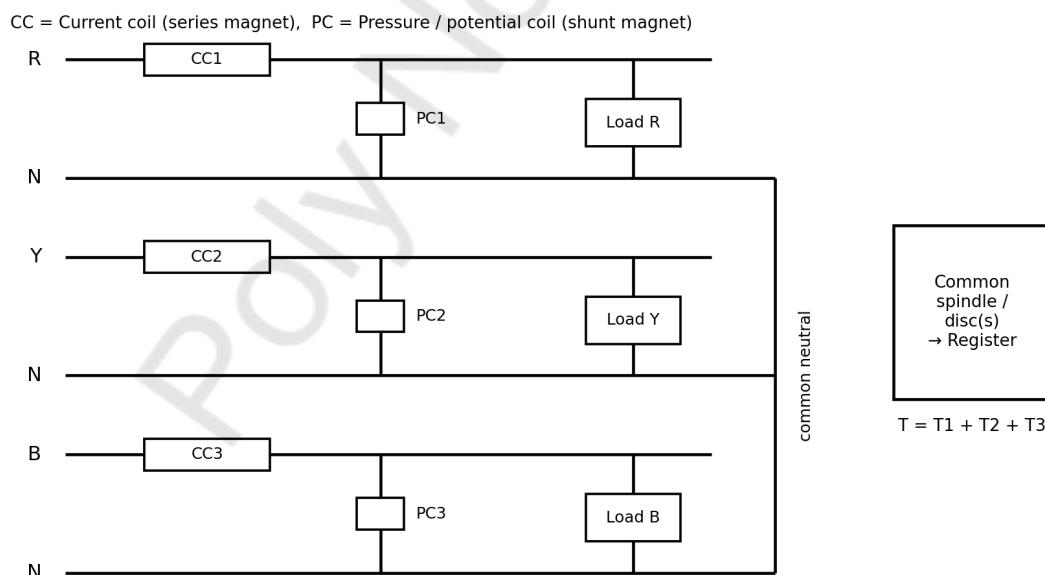


Fig. 4.4: Connection of a three-element (3-phase 4-wire) energy meter

Point	Single-phase meter	Three-phase meter
Measuring elements	One	Two (3-wire) or three (4-wire)

Point	Single-phase meter	Three-phase meter
Magnets	One shunt and one series magnet	One shunt and one series magnet for every element
Disc	One aluminium disc	One disc with two or three systems, or separate discs on one spindle
Torque	$T \propto V I \cos \phi$	Sum of the torques of all elements
Special adjustment	Lag, light load, brake	All of these plus torque balancing and interference compensation

4.2.5 Different Types of Errors and Their Compensation

The errors of an induction meter come from the driving system, the braking system, friction and external conditions. Each error is removed by a specific adjustment, as listed below.

Error	Cause	Compensation / Adjustment
Phase angle error	The shunt flux does not lag the supply voltage by exactly 90° , so torque is not proportional to $\cos \phi$. The error changes with power factor.	Lag adjustment: copper shading band (or lag coil) on the shunt magnet is moved or its resistance is changed until the lag is exactly 90° .
Speed error	Wrong magnitude of the fluxes or of the braking torque makes the meter run fast or slow.	Brake magnet adjustment: moving the magnet towards the rim increases braking and slows the meter; moving it towards the centre does the opposite.
Friction error	Friction in the bearings and gears opposes the small driving torque at light loads, so the meter runs slow.	Light load (friction) compensation: a shading loop or vane near the shunt magnet pole gives a small extra torque to overcome friction.
Creeping	Slow continuous rotation of the disc with only the pressure coil excited. It is caused by over-compensation of friction, excess voltage, vibration or stray fields.	Two small holes drilled at opposite points of the disc, or a small iron piece fixed on the spindle that is attracted to the shunt magnet and stops the disc.
Overload (self-braking) error	At heavy loads the series flux cuts the disc and creates an extra braking torque proportional to I^2 , so the meter runs slow.	Overload compensation: a magnetic shunt of saturable material across the series magnet that saturates at heavy load and reduces the extra braking effect.
Temperature error	Temperature changes affect the disc resistance and the strength of the permanent magnet.	A magnetic shunt of temperature-sensitive alloy across the brake magnet; use of stable magnet material.

Error	Cause	Compensation / Adjustment
Voltage variation error	Large voltage changes saturate the shunt magnet, so the flux is no longer proportional to voltage.	Designing the shunt magnet to work below saturation; use of a magnetic shunt on the shunt magnet.
Frequency variation error	Changes in frequency alter the fluxes and the eddy-current paths.	Mostly small; minimised by design and by phase (lag) adjustment.
External magnetic field error	Stray fields disturb the fluxes and the braking torque.	Magnetic shielding of the meter case; use of a symmetrical magnet system.
Wear and dust error	Worn bearings or dirt raise friction.	Regular maintenance, jewel bearing or magnetic suspension, sealed cases.

Summary of adjustments in an induction meter

Adjustment	Device used	Purpose
Lag adjustment	Copper shading band / lag coil	Make shunt flux lag the voltage by exactly 90° (power factor error)
Light load adjustment	Shading loop / vane on shunt magnet pole	Overcome friction at light load
Full load (speed) adjustment	Position of the permanent brake magnet	Set the speed correct at full load and unity power factor
Overload compensation	Saturable magnetic shunt on the series magnet	Remove the self-braking error at heavy load
Temperature compensation	Magnetic shunt on the brake magnet	Reduce error caused by temperature
Anti-creep device	Holes in disc / iron tag on spindle	Stop the disc at no load

4.3 Calibration of Single Phase Electronic Energy Meter Using Direct Loading

4.3.1 Meaning of Calibration

Calibration is the process of comparing the readings of a meter with those of a reference standard of higher accuracy, finding the error and, if necessary, adjusting the meter so that its error lies within the permitted limits of its accuracy class. The meter being checked is called the **Meter Under Test (MUT)** and the accurate instrument used for comparison is the **Reference Standard Meter (RSM)**. As a rule, the reference standard should be several times more accurate than the MUT.

Need for calibration

- To make sure that consumers are billed correctly.
- To detect drift in accuracy due to ageing and temperature.
- To set the gain and phase constants of a new electronic meter at the factory.
- To meet the requirements of the Indian Standards and the electricity regulations.

4.3.2 Direct Loading Method

In the **direct loading** (actual loading) method, the MUT and the reference standard are connected to the supply and a real load, such as a resistive load bank, lamp bank or rheostat, is connected in series with their current coils. The full load current actually flows through the meters and power is really consumed in the load. The energy recorded by the MUT is compared with that of the reference standard.

Point	Direct loading	Phantom loading
Load current	Passes through the real load	Supplied from a separate low-voltage source; no real load
Power consumption	High; the full power is wasted as heat	Very low
Equipment	Simple: load bank, supply, reference meter	Needs separate voltage and current sources
Suitable for	Small meters (low current ratings)	Large meters and test benches with many meters
Power factor setting	Needs inductive or capacitive loads (difficult)	Easy, by adjusting the phase of the sources

4.3.3 Apparatus Required

- Single-phase AC supply (230 V, 50 Hz), stable and nearly sinusoidal, with a variac or voltage regulator if required.

- Meter Under Test (MUT) – the single-phase electronic energy meter.
- Reference standard meter or precision power analyser of higher accuracy.
- Load: resistive load bank, lamp bank or rheostat (and an inductor for lagging power factor tests).
- Digital pulse counter or stopwatch with an optical pick-up for the calibration LED.
- Ammeter, voltmeter and power factor meter (if the reference does not show them), MCB and connecting wires.

4.3.4 Circuit Arrangement

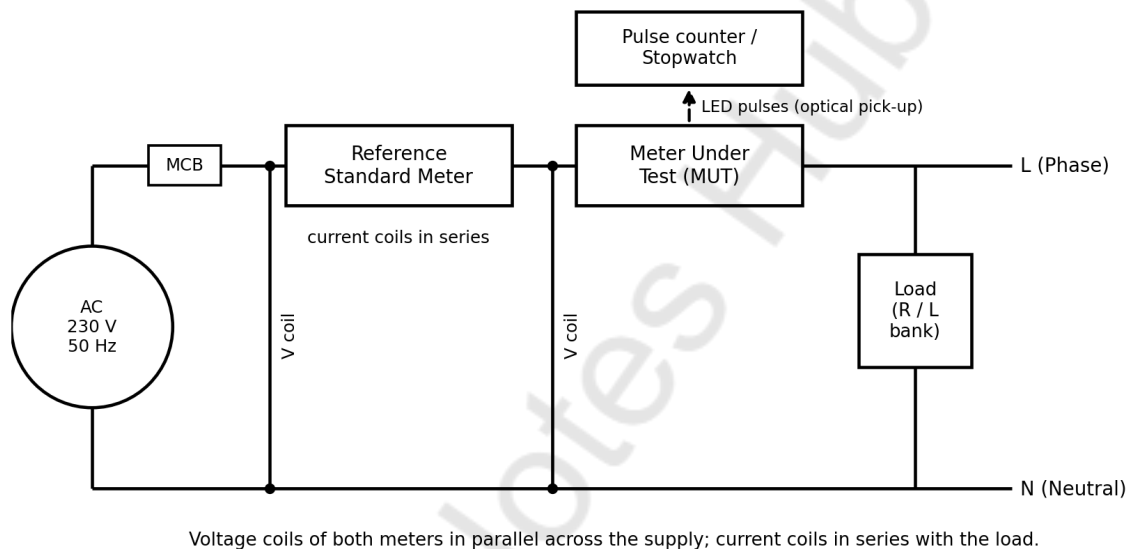


Fig. 4.5: Calibration of a single-phase electronic energy meter by direct loading

Conditions of test (reference conditions)

- The voltage and current circuits are energised for some time before starting (pre-conditioning or warm-up, usually about 30 minutes) so that the meter reaches a stable temperature.
- Supply voltage is at the rated value (within $\pm 1\%$) and frequency is at the rated value, with a sinusoidal waveform.
- Ambient temperature is the reference temperature, $27\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$, and there is no external magnetic field.
- The meter is mounted in its normal working position.

4.3.5 Procedure

1. Note the name-plate data of the MUT: rated voltage, I_b and I_{max} , meter constant (imp/kWh) and accuracy class.
2. Check the meter visually for damage, intact seals and a working display.

3. Connect the circuit as shown in Fig. 4.5. The current coils of the reference meter and MUT are in series with the load, and the voltage coils are in parallel across the supply.
4. Switch on the supply and wait for the warm-up time.
5. Set the load to the first test point (for example 10 % of I_b at unity power factor) and note the voltage, current and power from the reference meter.
6. Count a fixed number of pulses N from the MUT calibration LED and note the time t taken with the stopwatch (or compare the energy count of the MUT with the reference energy over the same period).
7. Calculate the energy recorded by the MUT and the true energy from the reference, and then the percentage error.
8. Repeat steps 5 to 7 at all the other test points, listed below.
9. If any error is beyond the permitted limit, adjust the calibration constants (gain and phase registers) of the meter with the calibration software and repeat the test.
10. Record all the readings in the observation table and prepare the calibration report.

Typical test points and error limits (Class 1.0 single-phase meter)

Current	Power factor	Permitted error
$0.05 I_b$ to $0.1 I_b$	1 (unity)	$\pm 1.5 \%$
$0.1 I_b$ to I_{max}	1 (unity)	$\pm 1.0 \%$
$0.1 I_b$ to $0.2 I_b$	0.5 lagging	$\pm 1.5 \%$
$0.2 I_b$ to I_{max}	0.5 lagging	$\pm 1.0 \%$

Note: The limits above are as given for class 1.0 meters in IS 13779 / IEC 62053-21. Students should refer to the latest edition of the standard for exact values.

Formulas used in calibration

Energy recorded by MUT, $E_m = N / K$ (kWh), where N = pulses counted, K = imp/kWh

True energy, $E_t = P \times t / (1000 \times 3600)$ (kWh), P in watts, t in seconds

$$\% \text{ Error} = (E_m - E_t) / E_t \times 100$$

When the pulse-timing method is used, the time that N pulses *should* take for a load of P watts is calculated and compared with the measured time:

$$t_{calc} = N \times 3600 \times 1000 / (K \times P) \text{ seconds}$$

$$\% \text{ Error} = (t_{calc} - t_{measured}) / t_{measured} \times 100$$

Example 4.3: A meter with $K = 3200 \text{ imp/kWh}$ is tested at a steady load of 1000 W (unity power factor). It gives 32 pulses in 36.2 s. Find the error.

$t_{\text{calc}} = 32 \times 3600 \times 1000 / (3200 \times 1000) = 36 \text{ s}$. % Error = $(36 - 36.2) / 36.2 \times 100 = -0.55 \%$. This is within $\pm 1.0 \%$, so the meter passes at this point.

Sample observation table

Sl. No.	Load current (A)	Power factor	Power P (W)	Pulses N	t measured (s)	t calc (s)	% Error
1	0.5	1.0	115	10	98.2	97.8	-0.41
2	5.0	1.0	1150	32	31.5	31.3	-0.63
3	10.0	1.0	2300	64	31.4	31.3	-0.32
4	5.0	0.5 lag	575	16	31.2	31.3	+0.32

The values in the table are typical illustrative values (for a 3200 imp/kWh meter at 230 V) to show the method of recording.

Other basic tests

- **No-load (creep) test:** the voltage circuit is supplied at 115 % of rated voltage with no current. The meter must not register more than one pulse in the specified period.
- **Starting current test:** the meter must start and keep registering at a very small current (about 0.4 % of I_b for class 1.0).

Precautions

- Check the polarity and the connections of current and voltage coils before switching on.
- Keep the load steady and the supply voltage and frequency constant during each reading.
- Place the optical pick-up exactly over the calibration LED and avoid stray light.
- Do not open the circuit of a CT-operated meter while it is loaded.
- Take readings only after the meter has warmed up; use sufficient pulses or time to reduce counting error.
- Keep the connecting leads of adequate size and the connections tight to avoid heating.

Advantages and limitations of direct loading

Advantages	Limitations
Simple circuit and low cost	A large amount of power is wasted as heat in the load
Test is done under actual working conditions	Difficult to obtain a large load current and different power factors
No special sources are required	Not suitable for large-current meters or for testing many meters together

Poly Notes Hub

Quick Revision: Key Formulas and Points

Quantity	Formula / Statement
Energy	$E = P \times t = V I \cos \phi \times t$; $1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$
Instantaneous power	$p = V I \cos \phi - V I \cos (2\omega t - \phi)$
Electronic meter constant	$K = \text{impulses per kWh}$; energy per pulse = $1000 / K \text{ Wh}$
Induction meter driving torque	$T_d \propto V I \cos \phi$
Induction meter speed	$N \propto P$ (since $T_b \propto N$ and $T_d = T_b$)
Energy recorded	$E_m = \text{Revolutions (or pulses)} / K$
Percentage error	$(E_m - E_t) / E_t \times 100$
Elements needed (Blondel)	$(n - 1)$ elements for an n -wire system
Phase angle between fluxes	$\beta = 90^\circ - \phi$
Pulse timing	$t_{\text{calc}} = N \times 3.6 \times 10^6 / (K \times P)$ seconds

Points to remember

- An energy meter is an integrating instrument; its unit is the kWh.
- Induction meter: shunt flux lags voltage by 90° ; series flux is in phase with current.
- Braking is by a permanent magnet; speed is proportional to power.
- Lag adjustment corrects power factor error; light-load adjustment corrects friction error; brake magnet position sets the speed.
- Creeping is stopped by holes in the disc or an iron tag on the spindle.
- Electronic meter errors are corrected by calibration of gain, phase and offset constants in the metering IC.
- Direct loading calibration uses a real load; it is simple but wastes power.

Multiple Choice Questions (15 MCQs)

Choose the correct answer.

Q1. The commercial unit of electrical energy is

- A) kW B) kWh C) kVA D) kVAR

Q2. An energy meter is basically an

- A) indicating instrument B) recording-only instrument C) null type instrument D) integrating instrument

Q3. The induction type energy meter works on the principle of

- A) interaction of alternating fluxes with eddy currents induced in an aluminium disc B) force between two fixed coils C) electrostatic attraction D) heating effect of current

Q4. In an induction type energy meter, the shunt magnet flux should lag the supply voltage by

- A) 0° B) 45° C) 90° D) 180°

Q5. The braking torque in an induction energy meter is produced by

- A) the shunt magnet B) a permanent magnet C) the series magnet D) the copper shading band

Q6. Creeping in an induction meter is prevented by

- A) drilling two opposite holes in the disc B) increasing the supply voltage C) increasing the turns of the current coil D) removing the brake magnet

Q7. The meter constant of an electronic energy meter is normally expressed in

- A) kWh/hour B) V/A C) Ω/kWh D) impulses/kWh

Q8. Friction error in an induction meter is compensated by

- A) moving the brake magnet B) a saturable shunt on the series magnet C) a light load (shading loop) adjustment D) a temperature shunt

Q9. Number of measuring elements needed for a 3-phase 4-wire energy meter is

- A) 2 B) 3 C) 4 D) 1

Q10. A meter of 3200 imp/kWh is connected to a 1 kW load. The time between two pulses is

- A) 0.3125 s B) 3.2 s C) 0.8 s D) 1.125 s

Q11. In an electronic energy meter, the block that converts sensed analog signals into digital samples is the

- A) ADC B) LCD C) EEPROM D) RTC

Q12. Calibration of an energy meter means

- A) replacing its disc or display B) increasing its full load current rating C) comparing it with a more accurate reference and adjusting it to keep error within limits D) cleaning its bearings

Q13. The main disadvantage of the direct loading method of calibration is that

- A) it cannot be used for single-phase meters B) no reference meter is needed C) a high voltage source is needed D) a large amount of power is wasted in the load

Q14. The percentage error of an energy meter is given by

- A) $(E_t - E_m) / E_m \times 100$ B) $(E_m - E_t) / E_t \times 100$ C) E_m / E_t D) $(E_m + E_t) / E_t \times 100$

Q15. Overload (self-braking) error of an induction meter is compensated by

- A) a saturable magnetic shunt across the series magnet B) a copper shading band on the shunt magnet C) holes in the disc D) reducing the strength of the brake magnet

Answer Key

Q. No.	Answer	Q. No.	Answer	Q. No.	Answer
1	B	6	A	11	A
2	D	7	D	12	C
3	A	8	C	13	D
4	C	9	B	14	B
5	B	10	D	15	A

Answers with option text

Q. No.	Correct answer
1	B) kWh
2	D) integrating instrument
3	A) interaction of alternating fluxes with eddy currents induced in an aluminium disc
4	C) 90°
5	B) a permanent magnet
6	A) drilling two opposite holes in the disc
7	D) impulses/kWh
8	C) a light load (shading loop) adjustment
9	B) 3
10	D) 1.125 s
11	A) ADC
12	C) comparing it with a more accurate reference and adjusting it to keep error within limits
13	D) a large amount of power is wasted in the load
14	B) $(E_m - E_t) / E_t \times 100$
15	A) a saturable magnetic shunt across the series magnet

Broad Questions (10 Questions)

- Q1.** Draw the block diagram of a single-phase electronic energy meter and explain the function of each block and its working principle.
- Q2.** Explain the working of a three-phase electronic energy meter. Compare the 3-phase 3-wire and 3-phase 4-wire meters and state Blondel's theorem.
- Q3.** Describe the different types of errors in an electronic energy meter and explain how each of them is compensated.
- Q4.** With a neat sketch, describe the constructional features of a single-phase induction type energy meter.
- Q5.** Derive the expression for the driving torque of an induction type energy meter and show that the number of revolutions of the disc is proportional to the energy consumed.
- Q6.** Explain the different errors in an induction type energy meter and the methods used to compensate them.
- Q7.** Explain the constructional features and working of a three-phase induction type energy meter. How is the interference between the elements avoided?
- Q8.** What is creeping? Explain how it is prevented. Explain also the friction (light load) compensation and overload compensation in an induction meter.
- Q9.** Describe, with a neat circuit diagram, the procedure for calibration of a single-phase electronic energy meter by the direct loading method. Draw a sample observation table and state the formulas used.
- Q10.** A single-phase electronic energy meter has a constant of 3200 imp/kWh. It gives 32 pulses in 30.5 s when connected to a steady load of 1.2 kW. Find the percentage error of the meter and say whether it is within the $\pm 1.0\%$ limit of a class 1.0 meter.