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ENERGY AUDIT, CONSERVATION & MANAGEMENT

UNIT-III

Power Factor and energy instruments

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POWER FACTOR IMPROVEMENT

Definition

The power factor of an AC electrical power system is defined as the ratio of the real power absorbed by the load to the apparent power flowing in the circuit, and is a dimensionless number in the closed interval of −1 to 1

The power factor of an AC electric power system is defined as the ratio of the **active (true or real) power** to the **apparent power**

Where

- **Active (Real or True) Power** is measured in watts (W) and is the power drawn by the electrical resistance of a system doing useful work.
- **Apparent Power** is measured in volt-amperes (VA) and is the voltage on an AC system multiplied by all the current that flows in it. It is the vector sum of the **active** and the **reactive power.**
- **Reactive Power** is measured in volt-amperes reactive (VAR). Reactive Power is power stored in and discharged by inductive motors, transformers and solenoids

Reactive power is required for the magnetization of a motor but doesn't perform any action. The reactive power required by inductive loads increases the amounts of apparent power - measured in kilovolt amps (kVA) - in the distribution system. Increasing of the reactive and apparent power will cause the power factor - PF - to decrease.

It is common to define the Power Factor - PF - as the cosine of the phase angle between voltage and current - or the "cosφ".

Power factor is an important measurement in electrical AC systems because

- an overall power factor less than 1 indicates that the electricity supplier need to provide more generating capacity than actually required
- the current waveform distortion that contributes to reduced power factor is caused by voltage waveform distortion and overheating in the neutral cables of three-phase systems

Example - Power Factor

An industrial plant draws 200 A at 400 V and the supply transformer and backup UPS is rated

200 A × 400 V = 80 kVA.
If the power factor - PF - of the loads is only 0.7-only
80 kVA × 0.7 = 56 kW

of real power is consumed by the system. If the power factor is close to 1 (purely resistive circuit) the supply system with transformers, cables, switchgear and UPS could be made considerably smaller.

Any power factor less than 1 means that the circuit's wiring has to carry more current than what would be necessary with zero reactance in the circuit to deliver the same amount of (true) power to the resistive load.

A low power factor is expensive and inefficient and some utility companies may charge additional fees when the power factor is less than 0.95. A low power factor will reduce the electrical system's distribution capacity by increasing the current flow and causing voltage drops.

"Leading" or "Lagging" Power Factors

Power factors are usually stated as "leading" or "lagging" to show the sign of the phase angle.

- With a purely resistive load current and voltage changes polarity in step and the power factor will be 1. Electrical energy flows in a single direction across the network in each cycle.
- Inductive loads - transformers, motors and wound coils - consumes reactive power with current waveform lagging the voltage.
- Capacitive loads - capacitor banks or buried cables - generates reactive power with current phase leading the voltage.

Inductive and capacitive loads stores energy in magnetic or electric fields in the devices during parts of the AC cycles. The energy is returned back to the power source during the rest of the cycles.

Typical Motor Power Factors

Power (hp)	Speed (rpm)	Power Factor		
		½ load	¾ load	full load
0 - 5	1800	0.72	0.82	0.84
5 - 20	1800	0.74	0.84	0.86
20 – 100	1800	0.79	0.86	0.89
100 - 300	1800	0.81	0.88	0.91

1 hp = 745.7 W

Methods of improvement

Power factor with Non-linear loads

A non-linear load on a power system is typically a rectifier (such as used in a power supply), or some kind of arc discharge device such as a fluorescent lamp, electric welding machine, or arc furnace. Because current in these systems is interrupted by a switching action, the current contains frequency components that are multiples of the power system frequency. Distortion power factor is a measure of how much the harmonic distortion of a load current decreases the average power transferred to the load.

Non-sinusoidal components

Non-linear loads change the shape of the current waveform from a sine wave to some other form. Non-linear loads create harmonic currents in addition to the original (fundamental frequency) AC current. Filters consisting of linear capacitors and inductors can prevent harmonic currents from entering the supplying system.
In linear circuits having only sinusoidal currents and voltages of one frequency, the power factor arises only from the difference in phase between the current and voltage. This is "displacement power factor". The concept can be generalized to a total, distortion, or true power factor where the apparent power includes all harmonic components. This is of importance in practical power systems that contain non-linear loads such as rectifiers, some forms of electric lighting, electric arc furnaces, welding equipment, switched-mode power supplies and other devices.

A typical multimeter will give incorrect results when attempting to measure the AC current drawn by a non-sinusoidal load; the instruments sense the average value of a rectified waveform. The average response is then calibrated to the effective, RMS value. An RMS sensing multimeter must be used to measure the actual RMS currents and voltages (and therefore apparent power). To measure the real power or reactive power, a watt meter designed to work properly with non-sinusoidal currents must be used.

LOCATION OF CAPACTIORS

Compensation can be carried out by a fixed value of capacitance in favorable circumstances. Sometimes compensation is more-commonly effected by means of an automatically controlled stepped bank of capacitors.

Note: when the installed reactive powers of compensation exceed 800kVAr and the load is continuous and stable, it is often found to be economically advantageous to install capacitor banks at high voltage.

Compensation at L.V:

At low voltage, compensation is provided by:

- Fixed-valued capacitor;
- Equipment providing automatic regulation or banks which allow continuous adjustment according to requirements, as loading of the installation changes.

- **Fixed Capacitors**

This arrangement employs one or more capacitor (s) to form a constant level of compensation. Control may be:

- Manual: by circuit breaker or load-break switch;
- Semi-automatic : by contactor;
- Direct connection to an appliance and switched with it.

These capacitors are applied:

- At the terminals of inductive devices(motor and transformers)
- At bus bars supplying numerous small motors and inductive appliance for which individual compensation would be too expensive;
- In cases where the level of load is reasonable constant.

- **Automatic Capacitor Banks**

This kind of equipment provides automatic control of compensation, maintain within close limits, a selected level of power factor. Such equipment is applied at points in an installation where the active power and/ or reactive -power variations are relatively large, for example:

- At the bus bars of a general power distribution board;

Power factor correction in non-linear loads

Passive PFC

The simplest way to control the harmonic current is to use a filter: it is possible to design a filter that passes current only at line frequency (50 or 60 Hz). This filter reduces the harmonic current, which means that the non-linear device now looks like a linear load. At this point the power factor can be brought to near unity, using capacitors or inductors as required. This filter requires large-value high-current inductors, however, which are bulky and expensive.

A passive PFC requires an inductor larger than the inductor in an active PFC, but costs less.
This is a simple way of correcting the nonlinearity of a load by using capacitor banks. It is not as effective as active PFC. One example of this is a valley-fill circuit.

Passive PFCs are typically more power efficient than active PFCs. Efficiency is not to be confused with the PFC, though many computer hardware reviews conflate them. A passive PFC on a switching computer PSU has a typical power efficiency of around 96%, while an active PFC has a typical efficiency of about 94%.

Active PFC

An "active power factor corrector" (active PFC) is a power electronic system that changes the wave shape of current drawn by a load to improve the power factor. The purpose is to make the load circuitry that is power factor corrected appear purely resistive (apparent power equal to real power). In this case, the voltage and current are in phase and the reactive power consumption is zero. This enables the most efficient delivery of electrical power from the power company to the consumer.

Some types of active PFC are:

- Boost
- Buck
- Buck-boost

Active power factor correctors can be single-stage or multi-stage.

In the case of a switched-mode power supply, a boost converter is inserted between the bridge rectifier and the main input capacitors. The boost converter attempts to maintain a constant DC bus voltage on its output while drawing a current that is always in phase with and at the same frequency as the line voltage. Another switch

mode converter inside the power supply produces the desired output voltage from the DC bus. This approach requires additional semiconductor switches and control electronics, but permits cheaper and smaller passive components. It is frequently used in practice.

For example, SMPS with passive PFC can achieve power factor of about 0.7–0.75, SMPS with active PFC, up to 0.99 power factor, while a SMPS without any power factor correction has a power factor of only about 0.55–0.65.

Due to their very wide input voltage range, many power supplies with active PFC can automatically adjust to operate on AC power from about 100 V (Japan) to 230 V (Europe). That feature is particularly welcome in power supplies for laptops.

EFFECT OF HARMONICS

Harmonics distortion disrupts plants of greatest importance is the loss of productivity. These occur because of process shutdowns due to the unexpected failure of motors, drives, power supplies or just the spurious tripping of breakers. In addition, maintenances and repair budgets can be severely stretched.

Table Effect of harmonics on various electrical equipment

EQUIPMENT	CONSEQUENCES
Capacitors	blown fuses, Reduced capacitor life
Motors	Inability of fully load, mechanical fatigue reduced motor life
Fuses/ breakers	False/ spurious operation and damaged components
Transformers	Increases copper and iron losses, reduced capacity, increased noise and possible insulation failure
Unility meters	Measurement errors/ higher billings
Telephones	interference (low frequency hum, noise)
Drives/ power supplies	Miss-operation due to multiple zero crossing
Cables	Increased copper loss

PF MOTOR CONTROLLERS

Power factor can also be improved by using synchronous motors which can be operated at leading power factor to compensate for loads with lagging power. These synchronous motors are normally operated at no mechanical load and over-excitation. Synchronous motors re very expensive and are used only in few industries. Following problems (from JNTU previous years question papers) describe these applications.

In recent years, solid-state control devices have been developed that,
when connected between a power source and an electric motor,

Single-Phase Motors

For application to single-phase motors, the power factor controller consists of a triac, sensing and control circuits, and a firing circuit for the triac, as shown in Fig. The power factor controller sensing circuit monitors the phase angle between the voltage and current and produces a signal proportional to the phase angle. This signal is compared to a reference signal that indicates the desired phase angle. This comparison produces an error signal that provides the timing for firing the triac or SCR and causes the phase angle to remain constant when the load changes. Typical motor voltage and current waveforms are shown in Figs. If the phase angle increases, the control circuit adjusts the triac firing angle to decrease the average voltage applied to the motor. Conversely, if the phase angle decreases, the control circuit adjusts the firing angle of the triac to increase the average voltage applied to

The power factor of the motor is the cosine of the phase angle between the motor voltage and current. Therefore, with this control system, by maintaining the phase angle constant, the motor operates at an approximately constant power factor over the load range. The maximum power factor is the power factor of the motor at the rated load with the triac full on. The minimum power factor will be determined by the minimum voltage setting for no-load operation. This voltage setting must be high enough to provide stable operation and prevent the motor from stalling on the sudden application of load. However, the lower the no-load voltage, the higher the power savings at no load.How are power savings achieved by decreasing the motor voltage at light loads? The motor losses can be grouped into three categories:

1. Constant losses, such as friction and windage
2. Magnetic core losses, which are some function of the applied voltage
3. I2R losses, which are a function of the square of the motor current, includ ing rotor losses

For a given load condition, the net losses, and hence the motor power input, decrease with a decrease in voltage as long as the magnetic core losses decrease more than the I2R losses increase. In addition, there is some increase in losses due to harmonics added to the motor input voltage by the triac switching and the losses in the controller.

In some instances, the increased harmonic content of the input voltage will result in increased motor noise.

The amount of power saved with a power factor controller depends on the duty cycle of the application. Typical power savings under various loads and duty cycles are shown in Fig. 4.24. The power savings are shown as a percent of the full voltage input and as a function of the percent running times at full load versus running at a light load. To result in significant power savings, at least 50%

Single-phase power factor motor controller power savings. of the running time should be at one-fourth load or less. Typical applications of this type may be drill presses and cutoff saws used in production processes. Figure 4.22 shows an oscilloscope picture of the motor voltage and current at no load for a single motor controlled by a power factor controller. Figure 4.23 shows an oscilloscope picture of the motor voltage and current of the same motor with load applied to the motor. Note the constant angle between the zero crossing of the voltage and current in both cases.

Three-Phase Motors

More recently, the application of power factor motor controllers has been extended to three-phase motors. In some cases, this has been accomplished by adding a power-saver module to existing

ENERGY INSTRUMENTS

DATA LOGGING

What is data logging?

It is the process of using a computer to collect data through sensors, analyze the data and save and output the results of the collection and analysis.

Data logging is commonly used in scientific experiments and in monitoring systems.

DATA LOGGER

A data logger (also data logger or data recorder) is an electronic device that records data over time or in relation to location either with a built in instrument or sensor or via external instruments and sensors.

They generally are small, battery powered, portable and equipped with a microprocessor, internal memory for data storage and sensors.

Some data loggers interface with a personal computer and utilize software to activate the data logger and view and analyze the collected data, while others have a local interface device (keypad, LCD) and can be used as a stand-alone device.

The sensors may communicate with the logger through a cable or wireless link and m ay sense temperature, humidity pressure flow, wind speed, current, voltage, resistance and most of other physical parameters that are important in monitoring and controlling processes.

One of the primary benefits of using data loggers is the ability to automatically collect data on a 24-hour basis.

DATA LOGGING Vs DATA ACQUISITION

The term data logging and data acquisition are used interchangeably. However in historical context they are quite different.

A data logger is a data acquisition system, but a data acquisition system is not necessarily a data logger.

Data loggers typically have slower sample rates.

APPLICATIONS

Soil moisture level recording. Road traffic counting

Vehicle testing

Monitoring of relays status in railway signaling

THERMOCOUPLES

Introduction

In electrical engineering and industry, thermocouples are widely used temperature sensors. They are cheap and interchangeable standard connectors, and can measure a wide range of temperatures.

Thermocouples alloys are commonly available as wires.

What is thermocouple sensor?

A thermocouple is a thermocouple device used to measure temperatures accurately. It consists of two dissimilar metals having different thermal and electrical properties joined together at one end so that potential difference generated between the contact points measures the temperature.

Principle of operation:

The principle is that when one junction is heated, an EMF is produced causing a current to flow round the loop. The EMF generated is given by logE = Alogt+B

Where t = temperature and A& B are constants depending upon the wires forming the junction.

Thermocouples Types:

A Thermocouple is available in different combinations of metals or calibrations. The four most common calibrations are J, K, and T & E.
The high temperature calibrations are R, S, and C & GB.
Other types of Thermocouples include beaded wire Thermocouple & Thermocouple probe.

How do we choose a Thermocouple type?

Thermocouples are very often used in industry as they are simple & can be used to measure wide range of temperatures

The following criteria are used in selecting a

thermocouple: Temperature range
Chemical resistance of thermocouple (or) sheath material.
Vibration resistance
Installation requirements.

Type K

Type K (chromel {90% nickel and 10% chromium}—alumel {95% nickel, 2% manganese, 2% aluminium and 1% silicon}) is the most common general purpose thermocouple with a sensitivity of approximately 41 µV/°C, chromel positive relative to alumel.[9] It is inexpensive, and a wide variety of probes are available in its −200 °C to +1250 °C / -330 °F to +2460 °F range. Type K was specified at a time when metallurgy was less advanced than it is today, and consequently characteristics may vary considerably between samples. One of the constituent metals, nickel, is magnetic; a characteristic of thermocouples made with magnetic material is that they undergo a deviation in output when the material reaches its Curie point; this occurs for type K thermocouples at around 350 °C. Wire color standard is yellow (+) and red (-).

It is the most commonly used for general purpose thermocouples. It is inexpensive and available in wide variety or probes.

They are available in -200^{0}C to 1350^{0}C range.

Type E

Type E (chromel–constantan) has a high output (68 µV/°C) which makes it well suited to cryogenic use. Additionally, it is non-magnetic. Wide range is −50 to 740 °C and Narrow range is −110 to 140 °C. Wire color standard is purple (+) and red (-).
It has high output (68µv/^{0}C) which makes it well suited for no. of applications.

Type J

Type J (iron–constantan) has a more restricted range than type K (−40 to +750 °C), but higher sensitivity of about 55 µV/°C. The Curie point of the iron (770 °C) causes an abrupt change in the characteristic, which determines the upper temperature limit. Wire color standard is white (+) and red (-).
It is less popular than K due to its limited range (-40^{0}C to 750^{0}C)

Type T

Type T (copper – constantan) thermocouples are suited for measurements in the −200 to 350 °C range. Often used as a differential measurement since only copper wire touches the probes. Since both conductors are non-magnetic, there is no Curie point and thus no abrupt change in characteristics. Type T thermocouples have a sensitivity of about 43 µV/°C.

It is available in the range of -200^{0}C to 350^{0}C.

COMMON THERMOCOUPLE TEMPARATURE RANGES

Calibration	**Temperature Range**	**Standard. limits of error**	**Specific. Limits of error**
J	0 C to 750 C	Greater than 2.2 C	Greater than 1.1 C
K	-200 C to 1250 C	Greater than 2.2 C	Greater than 1.1 C
E	-200 C to 900 C	Greater than 1.7 C	Greater than 1.0 C
T	-250 C to 350 C	Greater than 1.0 C	Greater than 0.5 C

Advantages & Disadvantages

Advantages

1. These are cheaper than the resistance thermometers.
2. These are very convenient for measuring the temperature at one particular point in a piece of apparatus.

Disadvantages

1. They have lower accuracy.
2. Complex Circuitry.

Applications

Thermocouples are most suitable for measuring over a large temperature range up to 1800^{0}C.

They are used as relays and also as protective devices in starters etc.

PYROMETER

Pyrometer is any non-contacting device that intercepts and measures thermal radiation.

This measure is used to determine temperature, often of the object's surface.

Pyrometer was originally coined to denote a device capable of measuring temperatures of objects above incandescence (i.e. objects bright to human eye).

Pyrometer is used for measurement of high temperature **RADIATION PYROMETER.**

Optical pyrometers work on the basic principle of using the human eye to match the brightness of the hot object to the brightness of a calibrated lamp filament inside the instrument.

The optical system contains filters that restrict the wavelength-sensitivity of the devices to a narrow wavelength band around 0.65 to 0.66 micons.

APPLICATIONS

Pyrometers are suited especially to the measurement of moving objects (or) any surfaces that can't be reached (or) can't be touched.

Pyrometers are used to measure wide temperature ranges above 1700^{0}C.

LUX METER

Lux meters (or) Light meters measures illumination in terms of luxes (lx).

A Lux is equal to the total intensity of light that falls on a one square meter surface i.e., one foot away from the point source of light.

Most lux meters consist of a body, light sensor & display.

The light that falls on to the light sensor contains energy i.e., converted to electric current. In turn the amount of current depends on the amount of light that strikes the light sensor. Lux meter read the electrical current, calculate the appropriate value and output the result to an analog, digital (or) video display.

The light usually contains different colors at different wavelengths; the reading represents the combined effects of all the wavelengths.

Typically standard colors (or) colors temperature are expressed in degrees klv. The standard color temperatures for the calibration of most lux meters is 2856^0K Selecting lux meter requires an analysis of performance specifications, display types & special features.

Performance specifications include sensor diameter, illumination range, accuracy, lux resolution, humidity range and optimum temperature range.

Several display types are available i.e. Analog devices display values on a dial usually with a needle (or) pointer.

Digital devices display values as numbers or letters.

Some lux meters are portable, handheld devices other are designed to sit atop desk or bench top.

Tongue testers

In electrical and electronic engineering, a **current clamp** or **current probe** is an electrical device having two jaws which open to allow clamping around an electrical conductor. This allows properties of the electric current in the conductor to be measured, without having to make physical contact with it, or to disconnect it for insertion through the probe. Current clamps are usually used to read the magnitude of a sinusoidal current (as invariably used in alternating current (AC) power distribution systems), but in conjunction with more advanced instrumentation the phase and waveform are available. Very high alternating currents (1000 A and more) are easily read with an appropriate meter; direct currents, and very low AC currents (milliamperes) are more difficult to measure.

Types of current clamp

Current transformer

A common form of current clamp comprises a split ring made of ferrite or soft iron. A wire coil is wound round one or both halves, forming one winding of a current transformer. The conductor around which it is clamped forms the other winding. Like any transformer this type works only with AC or pulse waveforms, with some examples extending into the megahertz range.

When measuring current, the subject conductor forms the primary winding and the coil forms the secondary.

This type may also be used in reverse, to inject current into the conductor, for example in EMC susceptibility testing to induce an interference current. Usually, the injection probe is specifically designed for this purpose. In this mode, the coil forms the primary and the test conductor the secondary.

Iron vane

In the iron vane type, the magnetic flux in the core directly affects a moving iron vane, allowing both AC and DC to be measured, and gives a true RMS value for non-sinusoidal AC waveforms. Due to its physical size it is generally limited to power transmission frequencies up to around 100 Hz.

The vane is usually fixed directly to the display mechanism of an analogue (moving pointer) clamp meter.

Hall Effect

The Hall Effect type is more sensitive and is able to measure both DC and AC, in some examples up to the kilohertz (thousands of hertz) range. This type was often used with oscilloscopes, and with high-end computerized digital multimeters, however, they are becoming common place for more general use.

Multi-conductor

Traditional current clamps will only work if placed around one conductor of the circuit under test because if it is placed around both, the magnetic fields would cancel. A relatively recent development is a clamp meter that has several sensor coils around the jaws of the clamp. This type can be clamped around standard 2 or 3 conductor single phase cables and will provide readout of the current flowing through the load. A version for three phase circuits does not currently exist, but in such circuits the individual conductors are usually accessible.

Clamp meter

An electrical meter with integral AC current clamp is known as a clamp meter, clamp -on ammeter or tong tester.

In order to use a clamp meter, only one conductor is normally passed through the probe; if more than one conductor is passed through then the measurement would be the vector sum of the currents flowing in the conductors and would depend on the phase relationship of the currents. In particular if the clamp is closed around a two-conductor cable carrying power to equipment the same current flows down one conductor and up the other, with a net current of zero. Clamp meters are often sold with a device that is plugged in between the power outlet and the device to be tested. The device is essentially a short extension cord with the two conductors separated, so that the clamp can be placed around only one conductor.

The reading produced by a conductor carrying a very low current can be increased by winding the conductor around the clamp several times; the meter reading divided by the number of turns is the current, with some loss of accuracy due to inductive effects.

Clamp meters are used by electricians, sometimes with the clamp incorporated into a general purpose multimeter.

It is simple to measure very high currents (hundreds of amperes) with the appropriate current transformer. Accurate measurement of low currents (a few milliamperes) with a current transformer clamp is more difficult.

Power Analyzer

A power analyzer is used to measure the flow of power (w) in an electrical system. This refers to the rate of electrical transferred between a power source and a sink, hence the alternative expression of power as energy per second (J/s). Measuring power flow is a critical yet rudimentary process that can be carried out with consummate ease using a standard power analyzer. More advanced systems acquire electrical signals and carry out integrated calculations for additional, complex analysis.

The Working Principles of Power Analyzers

Power analyzers can be used to measure the flow of energy in either alternating current (AC) or direct current (DC) systems – with distinct considerations for measuring AC circuits.

The determination of an electrical signal's True RMS time period underlines each of the subsequent calculations performed by the measuring instrument. This is complicated by AC measurements, where root mean square is typically expressed as an equivalent DC value. To accurately determine the True RMS of an AC waveform, an average must be calculated across the cycle of the AC frequency. This is defined as the fundamental frequency of the circuit. Power analyzers can digitally detect frequency cycles to provide reliable RMS periods during power conversion.

A power analyzer must also detect the voltage and current of the system. Typical systems directly acquire individual voltages using voltage dividers, while a transformer is usually required to measure the current. This may comprise a coil that measures the electrical field of a wire carrying a current, or a flux gate current transducer.

Once the power analyzer has determined each of these values, calculating power is a matter of simple mathematics.

Advanced Power Analysis

As mentioned, innovative power analyzers provide more than just power measurements. They are often required to measure various values of mechanical energy such as torque and speed, which are critical factors for test bench and manufacturing applications. This provides reliable data for comprehensive investigations into the performance and efficiency of electromechanical systems. Some of the additional calculations and analytical methods performed using advanced power analyzers include:

- Efficiency mapping;
- Fast Fourier Transform (FFT) and harmonic analysis;
- Fundamental power and root mean square (RMS) values;
- Polar diagrams and symmetrical components;
- Space vectors and DQ-currents.

Watt Hour Meter

Watt-hour meter is in fact a measuring device which can evaluate and records the electrical power passing through a circuit in a certain time. By implementing the Watt-hour meter, we can know how much amount of electrical energy is used by a consumer or a residence or an electrically powered device or a business. Electrical utilities install these meters at their consumer's place to evaluate the electrical usage for the purpose of billing. The reading is taken in each one billing period. Usually, the billing unit is Kilowatt-hour (kWh). This is equal to the total usage of electrical energy by a consumer of one kilowatt during a period of one hour and it is also equal to 3600000 joules. The Watt-Hour Meter is often referred as energy meter or electric meter or electricity meter or electrical meter.

Mainly the watt-hour meter comprises of a tiny motor and a counter. The motor will operate by diverting exact fraction of current which is flowing in the circuit to be measured.

The running or turning speed of this motor is directly proportional to the amount of current flow through the circuit. Thus, every revolution of the rotor of the motor is analogous to the given quantity of current flow in the circuit. A counter is attached to the rotor to add and the usage of electrical energy is displayed from the total number of rotor revolutions.