1- AND 3-PHASE ELECTRICAL POWER AND ENERGY MEASUREMENTS

theory, methods and instrumentation

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ELECTRICAL ENERGY & ELECTRIC POWER

Electric power, P, is defined as the rate at which electric energy, A (work), is transferred by an electric circuit.

If a charge, *dq,* due to voltage difference *V* flows between two points *A* and *B* $V=V_A-V_B$ *and if VA>VB, thus* the charage *dq carry out work* the work defined by:

$$dA = (V_A - V_B)dq = vdq$$

The voltage between two positions "A" and "B„, solid electrical conductors

Electric charge

and $$dq = idt$$ ⇨ $$dA = vidt$$

so

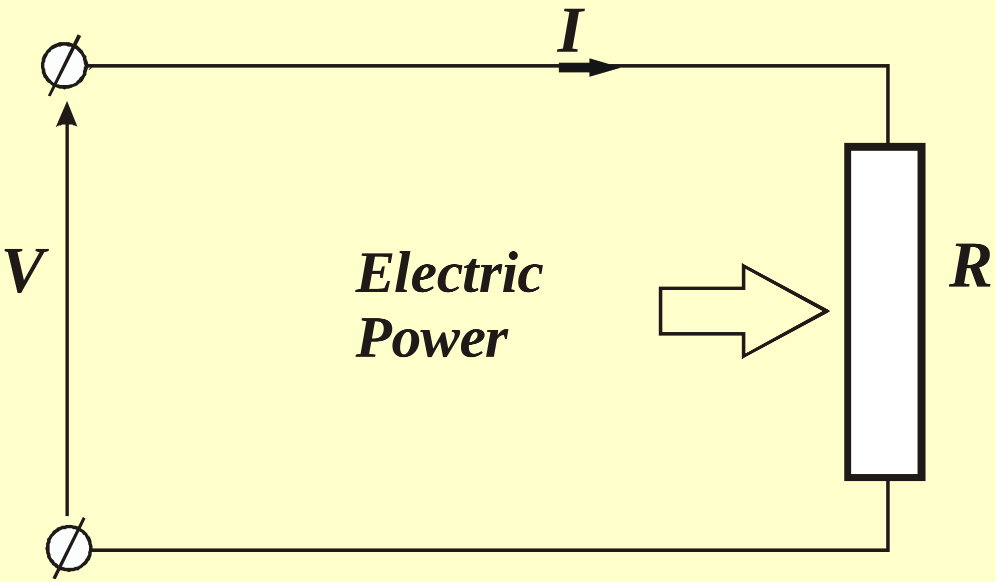
$$A = \int_0^T vidt$$

SI Unit for WORK, A is: J, Ws; Electrical energy kWs, kWh

SI Unit for POWER, P, is: W; J/s

DC ELECTRIC POWER

For direct current: $v = V \quad and \quad i = V$ $\qquad A = VIt$



$$P = \frac{A}{t} = \frac{QV}{t} = \frac{(It)V}{t} = VI \quad \text{unit W}$$

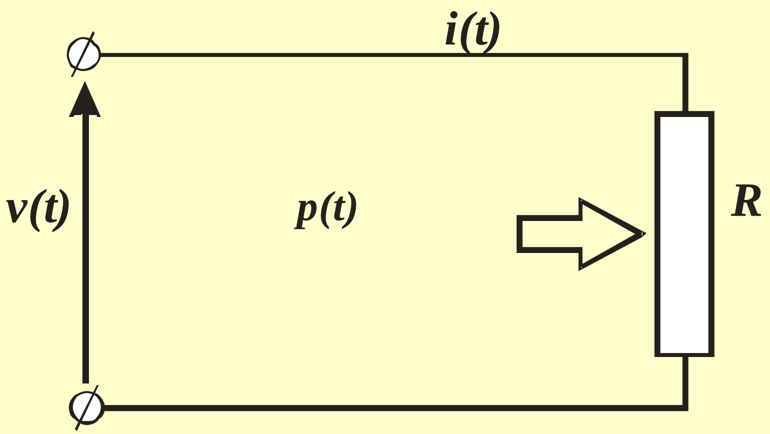
$$P = VI = (IR)I = RI^2 = V\left(\frac{V}{R}\right) = \frac{V^2}{R}$$

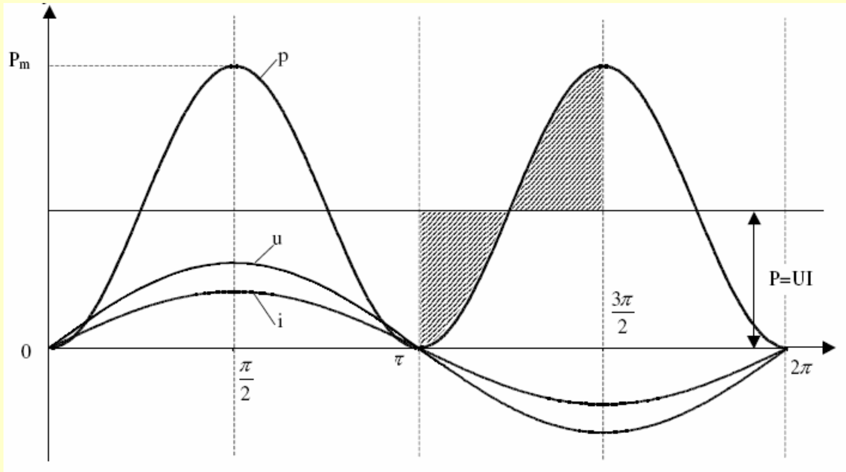
unit W

$$A = P \cdot t = V \cdot I \cdot t = RI^2 t = \frac{V^2}{R}t \quad \text{unit } 1\text{J}=1\text{W}\cdot\text{s}=1\text{N}\cdot\text{m}$$

(electric power meter kWh)

AC CURRENT (pure resistance load)





Multiplying *instantaneous* values of voltage and current, power is obtained

$$p = v(t)i(t) \qquad v(t) = V_m \sin(\omega t) = V_m \sin(2\pi f \cdot t)$$

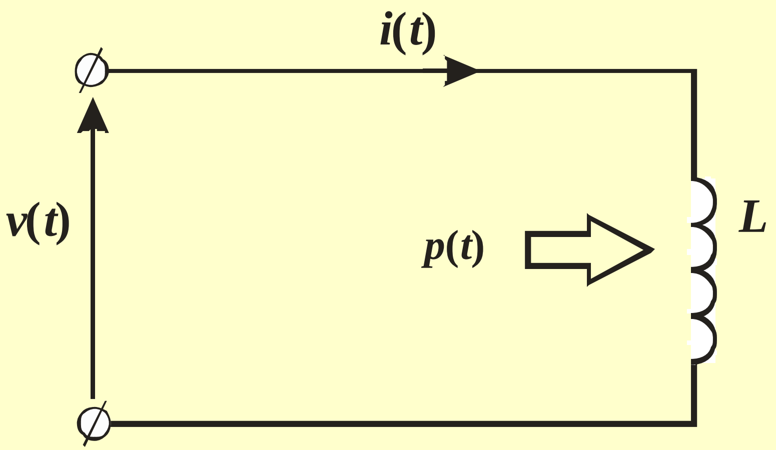
$$i(t) = I_m \sin(\omega t) = I_m \sin(2\pi f \cdot t)$$

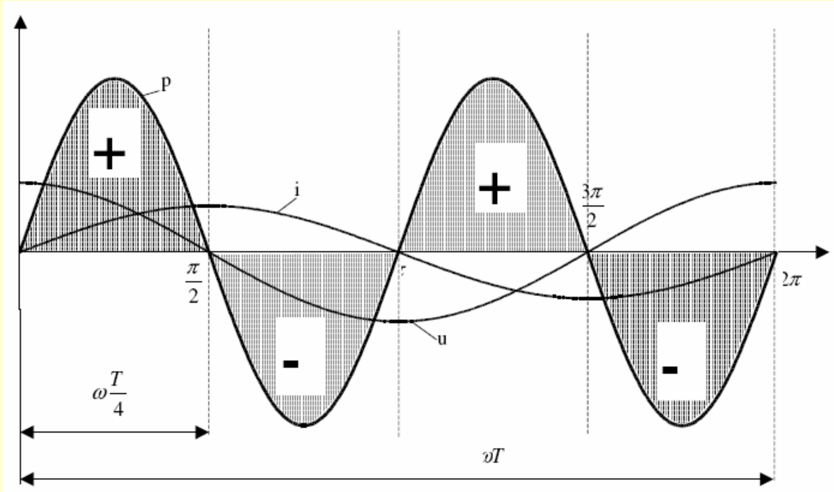
$$P = \frac{1}{T}\int_t^{t+T} p(t)dt = \frac{1}{T}\int_t^{t+T} v(t)i(t)dt = \frac{1}{T}\int_0^T V_m I_m \sin^2(2\pi f t)\,dt =$$

$$= V_m I_m \frac{1}{T}\int_0^T \sin^2(2\pi f t)\,dt = \frac{V_m I_m}{2} = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} = V_{eff} \cdot I_{eff}$$

$$P = \frac{1}{N}\sum_0^{N-1} v_i i_i$$

Reactive power and reactive energy





Solenoids or Capacitors, which are passive type elements induce reactive power and reactive energy

$$p = v(t)i(t)$$

$$\text{IF} \quad i(t) = I_m \sin(\omega t) = I_m \sin(2\pi f \cdot t)$$

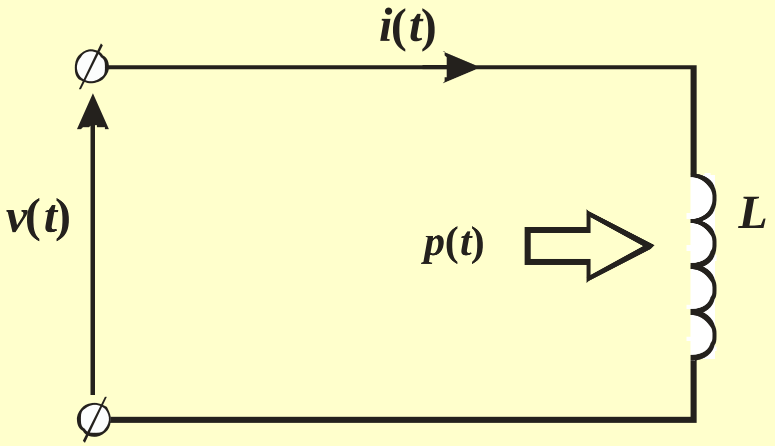
for inductance in circuitry $\quad v(t) = V_m \sin\left(\omega t + \frac{\pi}{2}\right) = V_m \sin\left(2\pi f \cdot t + \frac{\pi}{2}\right)$

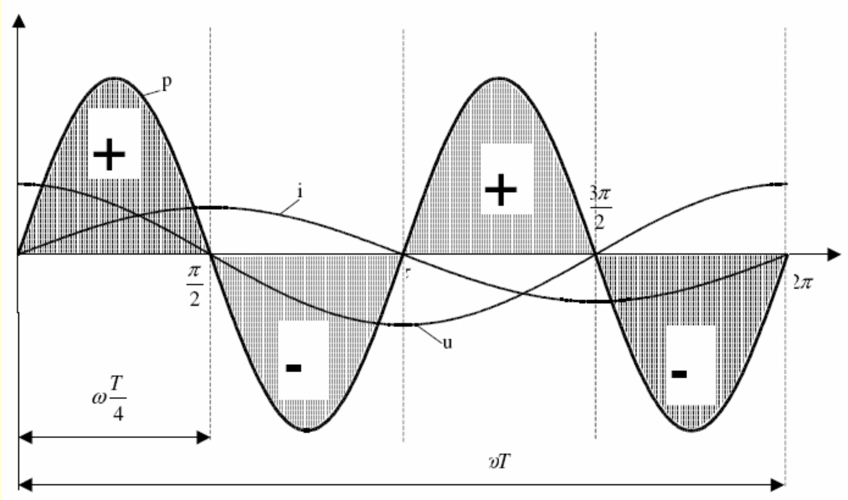
$$p(t) = v(t)i(t)d = V_m I_m \sin(\omega t)\sin\left(\omega t + \frac{\pi}{2}\right)$$

$$= V_m I_m \cdot \frac{1}{2}\sin(2\omega t) = V_{eff} I_{eff} \sin(2\omega t)$$

$$P = \frac{1}{T}\int_0^T p(t)dt = 0; \quad A = \int_0^T p(t)dt = 0;$$

Reactive power and reactive energy





No active power present but reactive power appears and exchange of power between magnetic field in solenoid and source of electric power occurs.

+ MARKS flow of energy from source to solenoid (magnetic energy concentrates

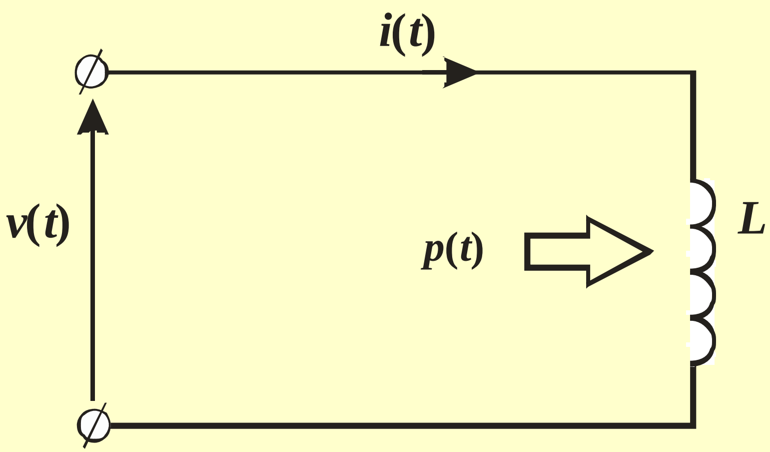
- MARKS flow of energy from solenoid to source

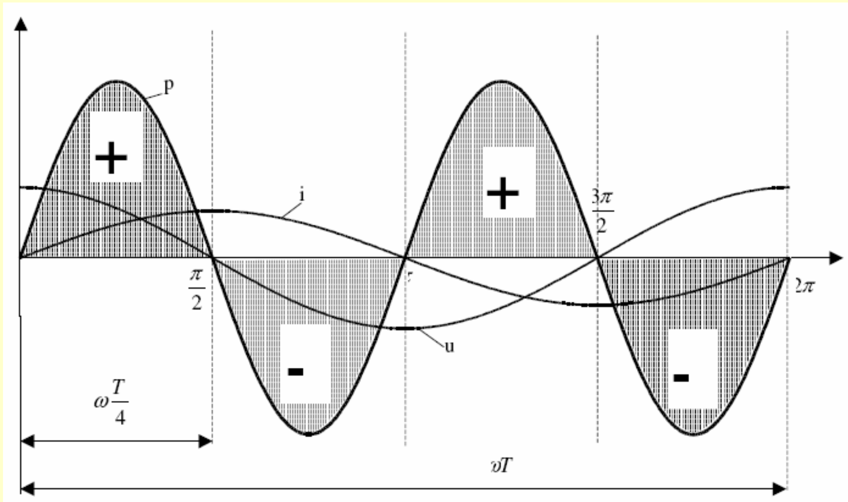
Not active but passive electric power (magnetic power) fluctuation occurs.

In the first quadrant current increases from 0 to I_m Magnetic flux induced by solenoid increases from o to Φ_m. The power from source is used to produce the magnetic power in solenoid:

$$A_{\frac{T}{4}} = \int_0^{\frac{T}{4}} v(t)i(t)dt = \int_0^{\frac{T}{4}} L\frac{di}{dt}i(t)dt = \int_0^{I_m} Lidi = L\frac{i^2}{2}\bigg|_0^{I_m} = \frac{LI_m^2}{2} = W_m$$

Reactive power and reactive energy





In the second quarter the current decreases from I_m to 0, emf of changes its direction, and cumulated energy W_m in solenoid is returned to source as magnetic field in solenoid disappears to 0. In the next two quarter that phenomena happens again and again. This appears only in circuitries without any resistance.

The flow of energy exists: current flows and voltage at the terminals of load appears.

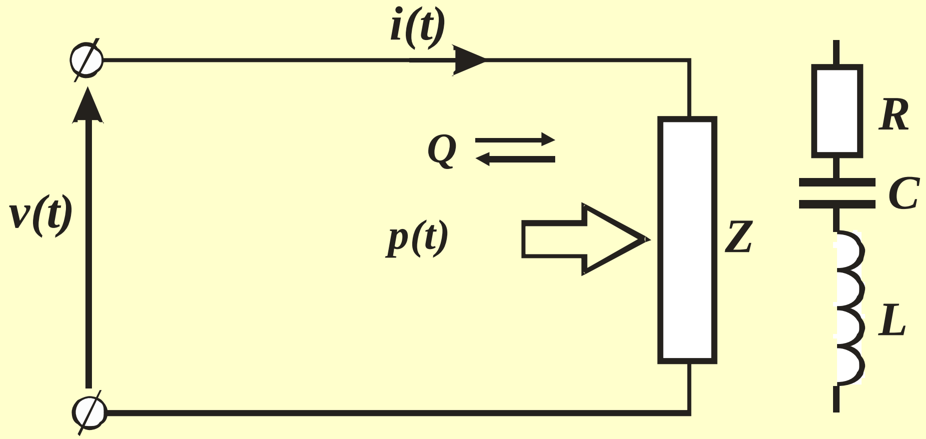
The product of I and V of which phase shift - angle of $\pi/2$ is called a reactive power (Q). The unit is 1 VAr

Energy A is called passive energy $A_{reactive}$= Qt. The unit is 1 VArs

For sampled data (voltage and current):

$$Q = \frac{1}{N}\sum_{0}^{N-1} v_i i_i \text{ where } i_i \text{ is a current data by } \frac{N}{4}$$

POWER & ENERGY FOR IMPEDANCE LOAD



$$p = v(t)i(t)$$

$$v(t) = V_m \sin(\omega t + \varphi_V)$$

$$i(t) = I_m \sin(\omega t + \varphi_I)$$

$$P = \frac{1}{T}\int_0^T p(t)dt = \frac{1}{T}\int_0^T v(t)i(t)dt = \frac{1}{T}\int_0^T V_m I_m \sin(\omega + \varphi_V)\sin(\omega + \varphi_I)dt =$$

$$= \frac{V_m I_m}{2}\cos(\varphi_V - \varphi_I) - \frac{V_m I_m}{2}\cos(2\omega t + \varphi_V + \varphi_I) =$$

$$= V_{eff} \cdot I_{eff} \cos(\varphi_V - \varphi_I) - V_{eff} \cdot I_{eff} \cos(2\omega t + \varphi_V + \varphi_I)$$

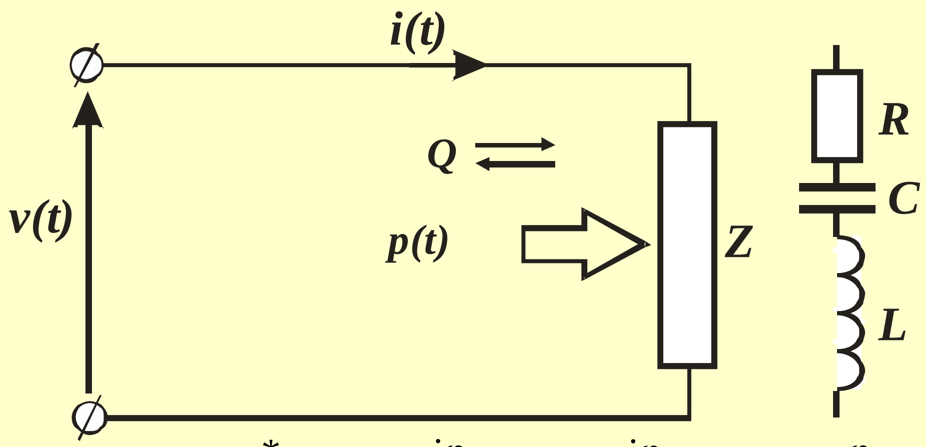
Active power

Reactive power

$$P = \frac{1}{N}\sum_0^{N-1} v_i i_i$$

$$Q = \frac{1}{N}\sum_0^{N-1} v_i i_i \text{ where } \mathrm{i_i} \text{ is a current data by } \frac{N}{4}$$

POWER & ENERGY FOR IMPEDANCE LOAD



Symbolic representation

$$\underline{V} = Ve^{j\varphi_V}$$

$$\underline{I} = Ie^{j\varphi_I} \qquad \underline{I}^* = Ie^{-j\varphi_I}$$

$$\underline{S} = \underline{V} \cdot \underline{I}^* = Ve^{j\varphi_V} \cdot Ie^{-j\varphi_I} = VIe^{\varphi_V - \varphi_I}$$

$$\underline{S} = VIe^{\varphi}$$

$$S = VI\cos\varphi + jVI\sin\varphi$$

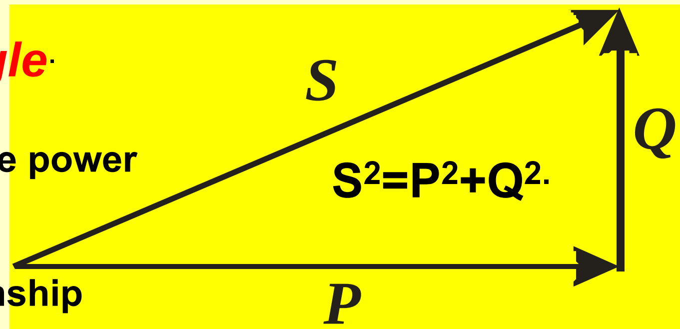
Q - REACTIVE

P ACTIVE

APPARENT

The apparent power vector is the hypotenuse of a right triangle formed by connecting the real and reactive power vectors

The *power triangle*.



reactive power is represented as a vertical vector

The relationship between real power, reactive power and apparent power can be expressed by representing the quantities as vectors.
Using the Pythagorean Theorem, the relationship among real, reactive and apparent power is:

$S^2=P^2+Q^2$.

Real power is represented as a horizontal vector

POWER IN SPACE

Electrical power flows wherever electric and magnetic fields exist together and fluctuate in the same place. The simplest example of this is in electrical circuits.

In the general case, however, the simple equation *P* = *IV* must be replaced by a more complex calculation, the <u>integral</u> of the <u>vector</u> <u>cross-product</u> of the electrical, *E*, and magnetic, *H*, fields over a specified area, *ds* thus:

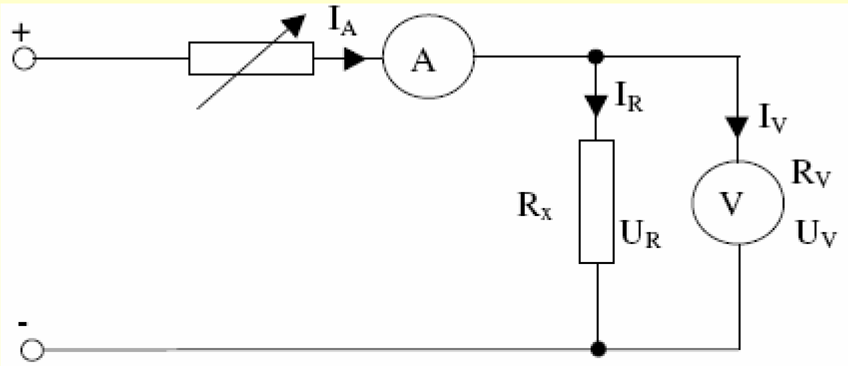
$$P = \int_S \left(E \times H \right) ds$$

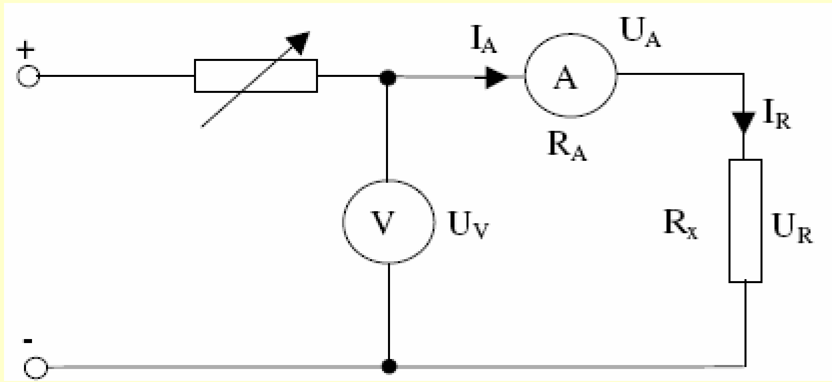
The result is a scalar since it is the surface integral of the Poynting vector.

DC POWER MEASUREMENT

Technical methods: constant current and constant voltage circuitries

$$P = V \cdot I$$





$$V_R = V_V \qquad I_A = I_R + I_V$$

$$V_V = V_A + V_R \qquad I_A = I_R$$

$$P = I_R \cdot V_V = (I_A - I_V) V_V = \\ = \left(I_A - \frac{V_V}{R_V} \right) V_V = I_A V_V - \frac{V_V^2}{R_V}$$

$$P = I_R \cdot V_R = I_A (V_V - V_A) = \\ = I_A (V_V - I_A R_A) = I_A V_V - I_A^2 R_A$$

CORRECTIONS

ENERGY = POWER * TIME

WATTMETERS: ANALOG vs. ELECTRONIC

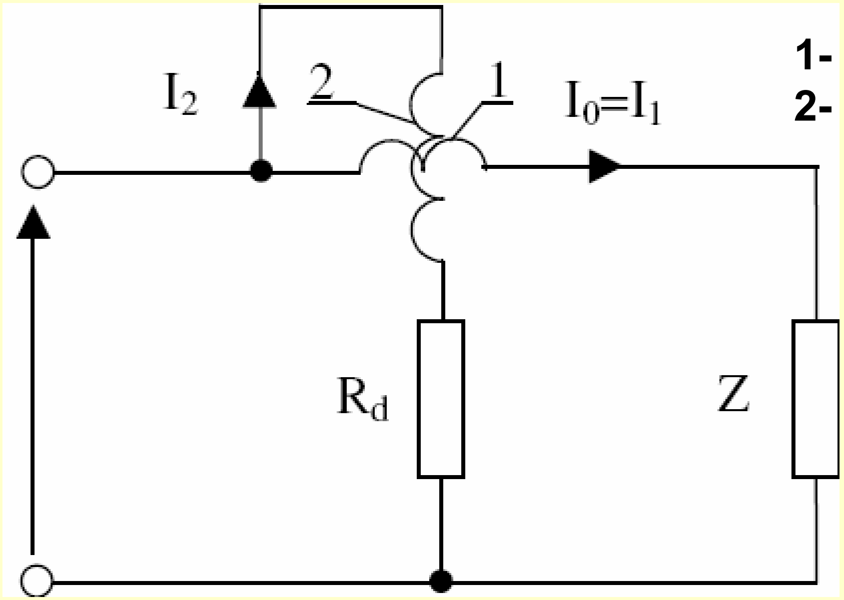
The traditional analog wattmeter is an electrodynamic instrument. The device consists of a pair of fixed coils, known as *current coils*, and a movable coil known as the *potential coil*. The current coils connected in series with the circuit, while the potential coil is connected in paralell. Also, on analog wattmeters, the potential coil carries a needle that moves over a scale to indicate the measurement. A current flowing through the current coil generates an electromagnetic field around the coil. The strength of this field is proportional to the line current and in phase with it. The potential coil has, as a general rule, a high-value resistor connected in series with it to reduce the current that flows through it.

The result of this arrangement is that on a dc circuit, the deflection of the needle is proportional to *both* the current *and* the voltage, thus conforming to the equation W=VA or $P=VI$. On an ac circuit the deflection is proportional to the average instantaneous product of voltage and current, thus measuring true power, and possibly (depending on load characteristics) showing a different reading to that obtained by simply multiplying the readings showing on a stand-alone voltmeter and a stand-alone ammeter in the same circuit.

The two circuits of a wattmeter can be damaged by excessive current. The ammeter and voltmeter are both vulnerable to overheating — in case of an overload, their pointers will be driven off scale — but in the wattmeter, either or even both the current and potential circuits can overheat *without* the pointer approaching the end of the scale! This is because the position of the pointer depends on the power factor, voltage and current. Thus, a circuit with a low power factor will give a low reading on the wattmeter, even when both of its circuits are loaded to the maximum safety limit. Therefore, a wattmeter is rated not only in watts, but also in volts and amperes

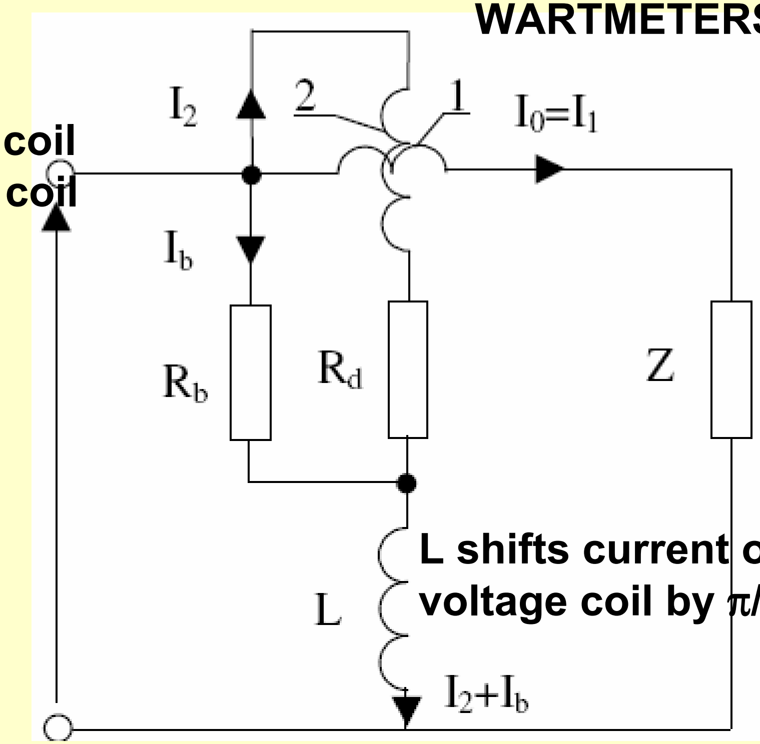
WATTMETERS: ANALOG vs. ELECTRONIC

WATTMETERS



1- current coil
2- voltage coil

WARTMETERS



L shifts current of voltage coil by $\pi/2$ rad

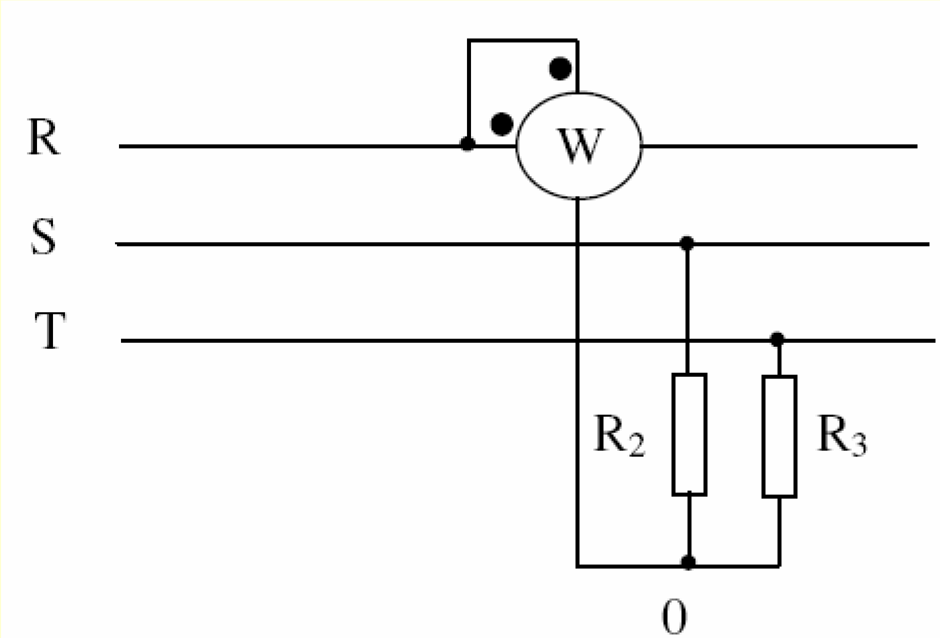
$$P = VI\cos\varphi$$

$$S = VI$$

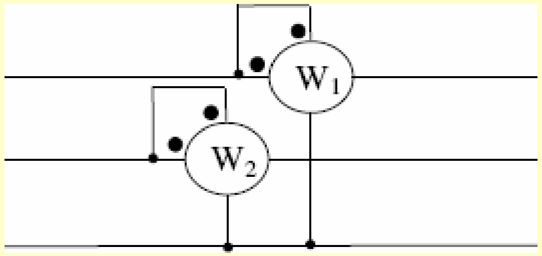
$$Q = VI\sin\varphi$$

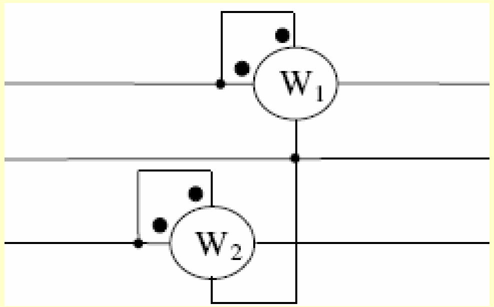
The above applies only for sinusoidal current and Voltage
Only electronic instruments are used for distorted current and voltage, but still watch the correctness of indications

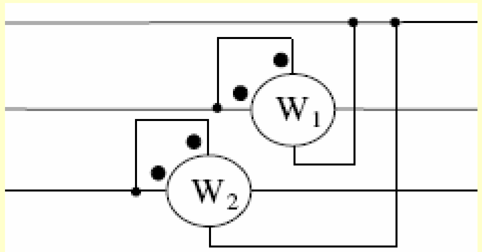
Configurations for 3 phase measurements



3 – wire Symetrical power supply and symetricalload



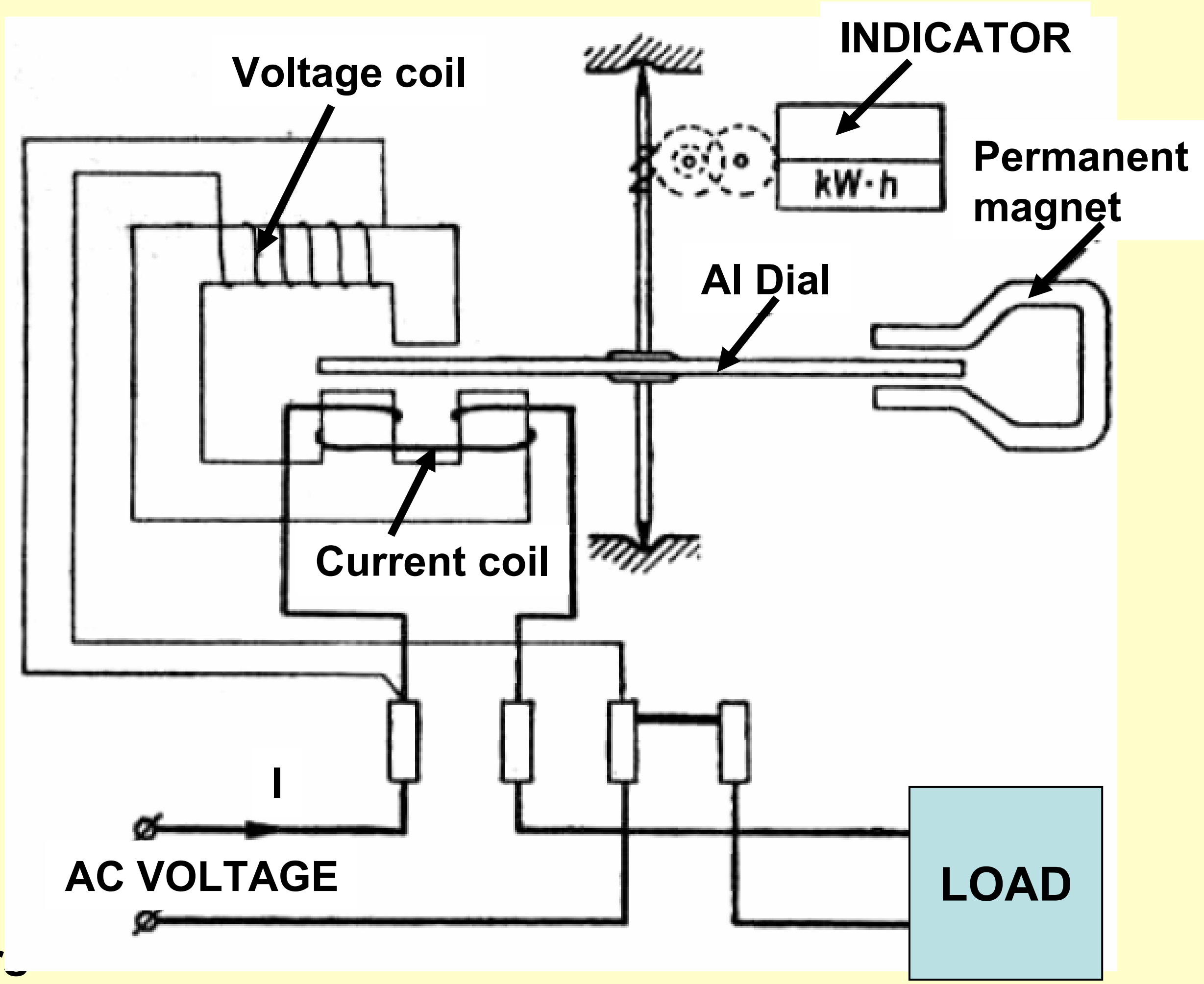




So called Aron configuration for 3 – wire no required symmetry of power supply and load. For power and energy meters

AN ELECTRIC METER OR ENERGY METER

An **electric meter** or **energy meter** is a device that measures the amount of electrical energy supplied to or produced by a residence, business or machine



Electromechanical meters

Electromechanical meters

1-phase AC supply

3-phase electromechanical induction meter,

The electromechanical induction meter operates by counting the revolutions of an aluminium disc which is made to rotate at a speed proportional to the power.
The number of revolutions is thus proportional to the energy usage. It consumes a small amount of power, typically around 2 watts.
The metallic disc is acted upon by two coils. One coil is connected in such a way that it produces a magnetic flux in proportion to the voltage and the other produces a magnetic flux in proportion to the current. The field of the voltage coil is delayed by 90 degrees using a lag coil. This produces eddy currents in the disc and the effect is such that a force is exerted on the disc in proportion to the product of the instantaneous current and voltage. A permanent magnet exerts an opposing force proportional to the speed of rotaion of the disc. The equilibrium between these two opposing forces results in the disc rotating at a speed proportional to the power being used.
The disc drives a register mechanism which integrates the speed of the disc over time by counting revolutions,in order to render a measurement of the total energy used over a period of time.

Electronic wattmeter

A modern digital electronic wattmeter/energy meter samples the voltage and current thousands of times a second. The average of the instantaneous voltage multiplied by the current is the true power. The true power divided by the apparent volt-amperes (VA) is the power factor. A computer circuit uses the sampled values to calculate RMS voltage, RMS current, VA, power (watts), power factor, and kilowatt-hours. The simple models display that information on LCD. More sophisticated models retain the information over an extended period of time, and can transmit it to field equipment or a central location.

Electronic wattmeters are used for direct, small power measurements or for power measurements at frequencies beyond the range of electrodynamometer-type instruments

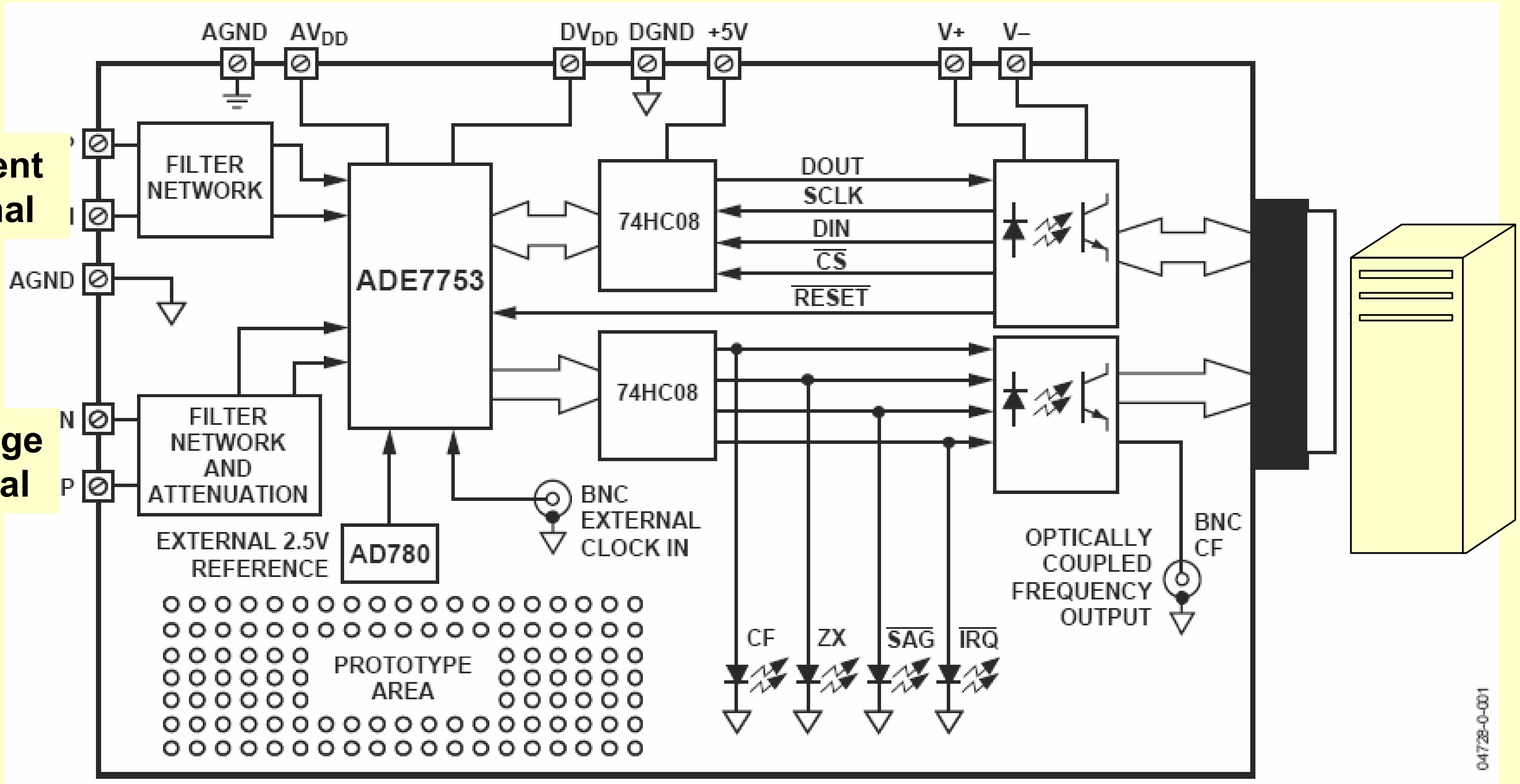
ADE7753

The ADE7753 is a high accuracy electrical power measurement IC with a serial interface and pulse output. The ADE7753 incorporates two second-order Σ-Δ ADCs, reference circuitry, temperature sensor, and all the signal processing required to perform active, reactive, and apparent energy measurement.

Power supply DF1743005C

Current signal

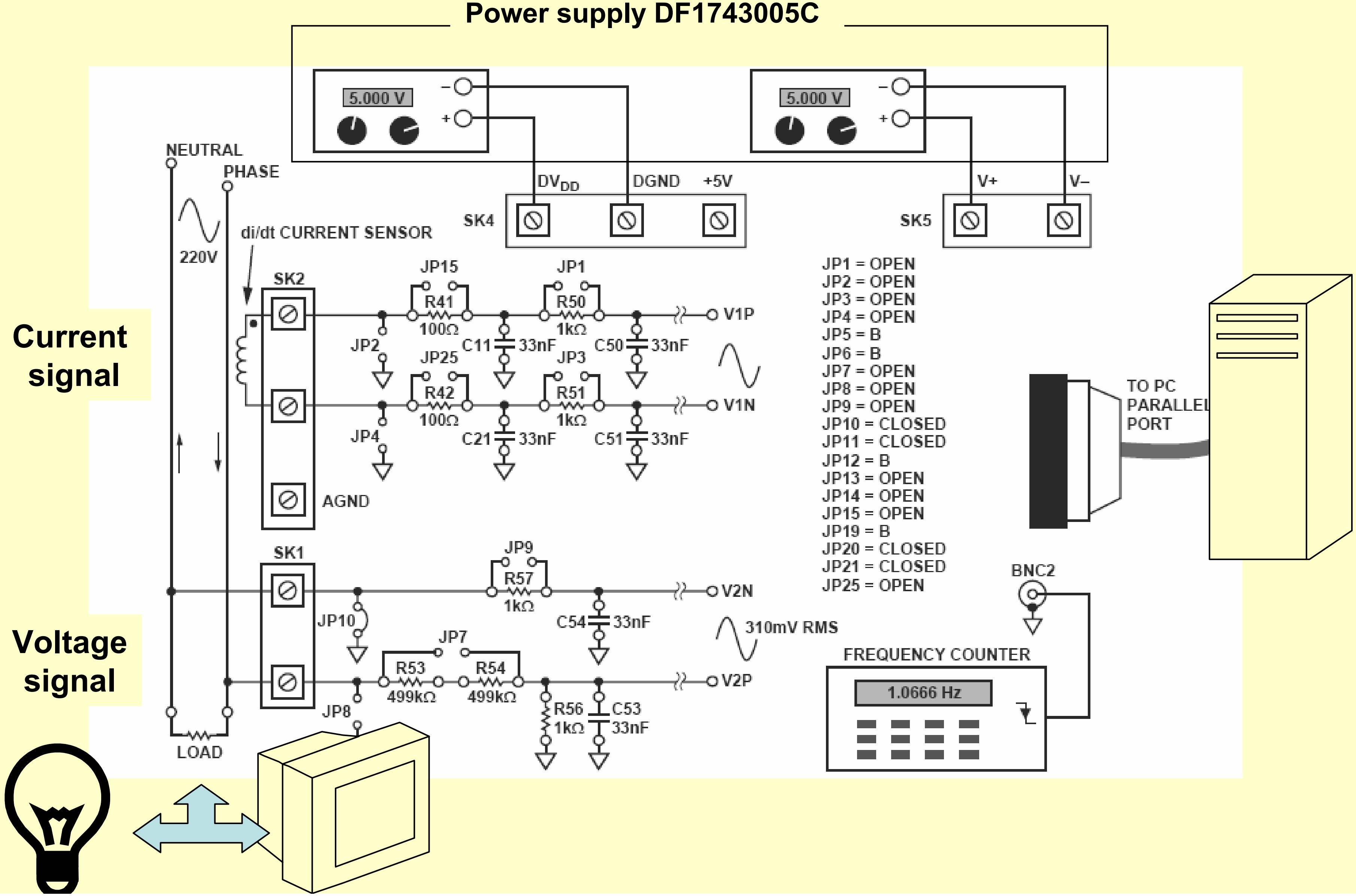
Voltage signal



Setup of ADE7753 Evaluation Board

Current signal

Voltage signal



Electronic Single Phase Watt-hour Meter

LAP- 1-phase multi tariff electricity meter for active energy measurement with load profile and maximum demand registration

Electronic Single Phase Watt-hour Meter

Electrical Features

Accuracy Class	Class 1.0
Rated Voltage	220/380 V – 240/415V
Rated Frequency	50/60Hz
Start Current	0.02%Ib
Voltage Circuit Power Consumption	<=0.8W,4VA
Current Circuit Power Consumption	<=0.1VA
Display	LED
Nominal Current	5A、10A、20A

Adopts large-scale IC, the latest micro-electronic technologies and SMT techniques.
1) long life, high accuracy, 2) high reliability, 3) high allowable overload, 4) little power consumption, 5) small size & light weight 6)Multi-tariff and Interval Energy Measurement. The tariff table, backup rate table and automatic conversion time for backup rate table can also be programmed and set at the customer' disposal,

Infrared communication, RS-485 communication function, the setting or cancel of the displaying contents, clock setting, intervals programming and data-collection can be achieved.
The Function of Automatic Data Transfer Transfer the data of last month automatically on the date and hour settled for automatic transfer. The data can be reserved for 100 years after power failure.