Measurement and Instrumentation

(Course Code: BEL04002)

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Gyan Ranjan Biswal received his B.E. in Electronics Engineering from the Pt. Ravishankar Shukla University, India in 1999 and M. Tech. (Honors) in Instrumentation & Control Engineering from the Chhattisgarh Swami Vivekananda Technical University, India in 2009 followed by Ph.D. in Electrical Engineering, specialized in the area of Power System Instrumentation (Power Generation Automation) from the Indian Institute of Technology Roorkee, India in 2012.

He is expertise in Design and Development of cooling systems for large size electrical generators, and the C&I of process industries. He has been in academia for about twelve years. Presently, he is with VSS University of Technology, Burla, India at the capacity of Head and Associate Professor, EEE from Dec. 2016. He has more than 70 publications in various Journals and Conferences of Internationally repute to his credit. He also holds a patent as well, and filed one more. He also adapted one international edition book published by Pearson India. He received research grants of US$90,000 (INR 53 lakhs). He has been supervised 01 PhD thesis and 09 Masters' theses. He has also been recognized with many national and international awards by elite bodies. He has been awarded with CICS award under the head of Indian National Science Academy for travel support to USA, MHRD Fellowship by Govt. of India, and Gopabandhu Das Scholarship in his career. His major areas of interests are Power System Instrumentation, Industrial Automation, Robust and Intelligent Control, the Smart Sensors, IoT enabled Smart Sensors, the Smart Grid, Fuel Cell lead Sustainable Sources of Energy, and System Reliability.

Dr. Biswal is a Fellow IE (India), Senior Member of IEEE, USA, and Life Member of ISTE, India. He is actively involved in review panels of different societies of international repute viz. IEEE, IFAC, and the ISA. Currently, he is also actively involved as a Member of IEEE–SA (Standards Association) working groups; IEEE P1876 WG, IEEE P21451-001 WG, and IEEE P1415. He has also been invited for delivering guest lectures at World Congress on Sustainable Technologies (WCST) Conf. 2012, London, UK, INDICON 2015, New Delhi, India, National Power Training Institute (NPTI), Nangal, India, and G.B. Pant Engineering College, Pauri, Gharwal, India, Surendra Sai University of Technology (formerly UCE), Burla, and as a guest expert in 2016 IEEE PES General Meeting Boston, MA, USA.

Syllabus

MODULE-I (8 HOURS) [Online mode: 6 HOURS + 1 Test]

Measuring Instruments: Classification, Absolute and secondary instruments, indicating instruments, deflecting, control and damping torques, Ammeters and Voltmeters, PMMC, Moving Iron (MI) type, expression for the deflecting torque and control torque, extension of range using shunts and series resistance. Electrostatic Voltmeters-electrometer type and attracted disc type, extension of range of E.S. Voltmeters.

MODULE-II (8 HOURS) [Online mode: 4 HOURS + 1 Test]

Electrodynamometer type wattmeter – Theory & its errors – Methods of correction – LPF wattmeter – Phantom loading – Induction type KWH meter – Calibration of wattmeter, energy meter. Measurement of active and reactive powers in balanced and unbalanced systems.

Galvanometers: General principle and performance equations of D'Arsonval Galvanometers, Vibration Galvanometer and Ballistic Galvanometer.

MODULE-III (8 HOURS) [Online mode: 6 HOURS + 1 Test]

DC/AC Bridges: General equations for bridge balance, measurement of self-inductance by Maxwell's bridge (with variable inductance & variable capacitance), Hay's bridge, Owen's bridge, measurement of capacitance by Schearing bridge, errors, Wagner's earthing device.

Method of measuring low, medium and high resistance: Kelvin's double bridge for measuring low resistance, Wheat-stone's bridge, measurement of high resistance – loss of charge method.

MODULE-IV (8 HOURS) [Online mode: 4 HOURS + 1 Test]

Instrument Transformers: Potential and current transformers, ratio and phase angle errors, phasor diagram, methods of minimizing errors.

Potentiometers: DC Potentiometer, Crompton potentiometer, construction, standardization, application. AC Potentiometer, Drysdale polar potentiometer; standardization, application.

MODULE-V (7 HOURS) [Online mode: 5 HOURS + 1 Test]

Digital Multi-meter: Block diagram, principle of operation, Accuracy of measurement, Electronic Voltmeter: Transistor Voltmeter, Block diagram, principle of operation, various types of electronic voltmeter, Digital Frequency meter: Block diagram, principle of operation.

Definition of transducers, Classification of transducers, Advantages of Electrical transducers, Characteristics and choice of transducers; Principle operation of LVDT and capacitor transducers; LVDT Applications, Strain gauge and its principle of operation, gauge factor.

Text and Reference Books

Recommended Text Books:

1. Helfrick & Cooper, "Modern Electronic Instrumentation and Measurement Techniques", PHI Publishers.

Reference Books:

* Golding & Waddis, "Electrical Measurement and Measuring Instruments", Reem Publishers.
* David A. Bell, "Electronic Instrumentation and Measurements", 3rd ed., Oxford University Press.
* P. Purkait, B. Biswas, S. Das and C. Koley, "Electrical and Electronics Measurement and Measuring Instruments", McGraw Hills.

Other Important References

Reference Sites and Acknowledgement to:	
1.	NPTEL, The National Programme on Technology Enhanced Learning (NPTEL): https://nptel.ac.in/
2.	Michigan State University, USA

Course Outcomes

Upon successful completion of this course, you (students) will be able to

CO1	**Understand the principles of basic electrical measuring instruments.**
CO2	Understand the operation of wattmeter, energy meter and galvanometers.
CO3	Understand and analyze the working of different ac and dc bridges.
CO4	Understand the operation of instrument transformers and potentiometers.
CO5	Understand the operation of electronic measuring instruments and transducers.

Wattmeter, Energy meter and Galvanometers

Power Measurement

The power measurements are made with the help of a wattmeter. Wattmeter is an indicating deflecting type of instrument used in laboratories for measurement of power in various ranges. A wattmeter consists of two coils as shown in the schematic representative figure 3.1

Current coil (CC): connected in series with circuit and carries the load current. It is designed such that it is wound with 2 to 3 turns of thick wire and hence it has a very low resistance.

Voltage or Pressure or Potential coil (PC): connected across the load circuit and hence carries a current proportional to the load current. The total load voltage appears across the PC. It is designed such that it is wound with several turns of thin wire and hence it has a very high resistance.

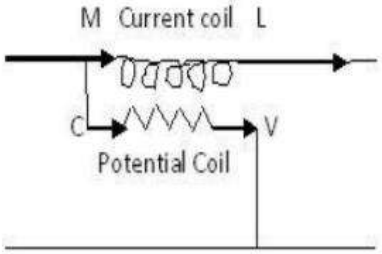


Fig. 3.1 Wattmeter Connections

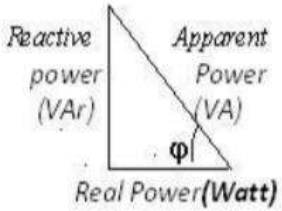
The wattmeter can be a UPF meter or LPF meter depending on the type of the load connected in the measuring circuit. For power measurements in AC circuits, the *wattmeter* is widely adopted. In principle and construction, it is a combination of those applicable for an ammeter and a voltmeter.

The electrical power can be of three forms:

Real power or simply, the power is the power consumed by the resistive loads on the system. It is expressed in watts (W). This is also referred as true power, absolute power, average power, or wattage.

Reactive power is the power consumed by the reactive loads on the system. It is expressed in reactive volt-amperes (VAr).

Apparent power is the vector sum of the above two power components. It is expressed in volt-amperes (VA).



Power Measurement

❖ Power in DC circuits

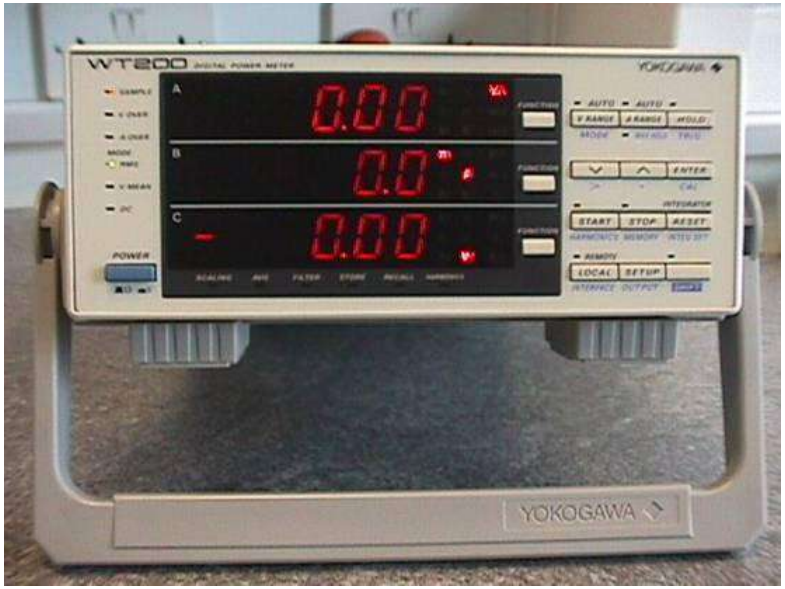
1. Power can be measured using a voltmeter and an ammeter (generally)

2. Two measurement arrangements

3. Wattmeter:
   I. Dynamometer
   II. Digital wattmeter
   III. Thermal wattmeter
   IV. Hall-power meter

Digital wattmeter (up to 100 kHz)

- Benefits:
  - High-resolution
  - Accuracy
- Convolution of signals
- Electronic multiplier is an analog system which gives as its output a voltage proportional to the power indication required → A/D conversion



Electrodynamometer
(Electrodynamics) Type Instruments

❖ Problem with other measuring instruments

- The necessity for the a.c. calibration of moving iron instruments as well as other types of instruments, which cannot be correctly calibrated, **requires the use of a transfer type of instrument**.
- A **transfer instrument** is one that may be calibrated with a d.c. Source and then used without modification to measure a.c.
- This requires the transfer type instrument to have the same accuracy for both d.c. and a.c., which the electrodynamometer instruments have.
- These standards are precision resistors and the Weston standard cell (which is a d.c. cell).
- It is obvious, therefore, that it would be impossible to calibrate an a.c. instrument directly against the fundamental standards.

Construction

Fixed Coils

- The field is produced by a fixed coil.
- This coil is divided into two sections to give a more uniform field near the centre and to allow passage of the instrument shaft.

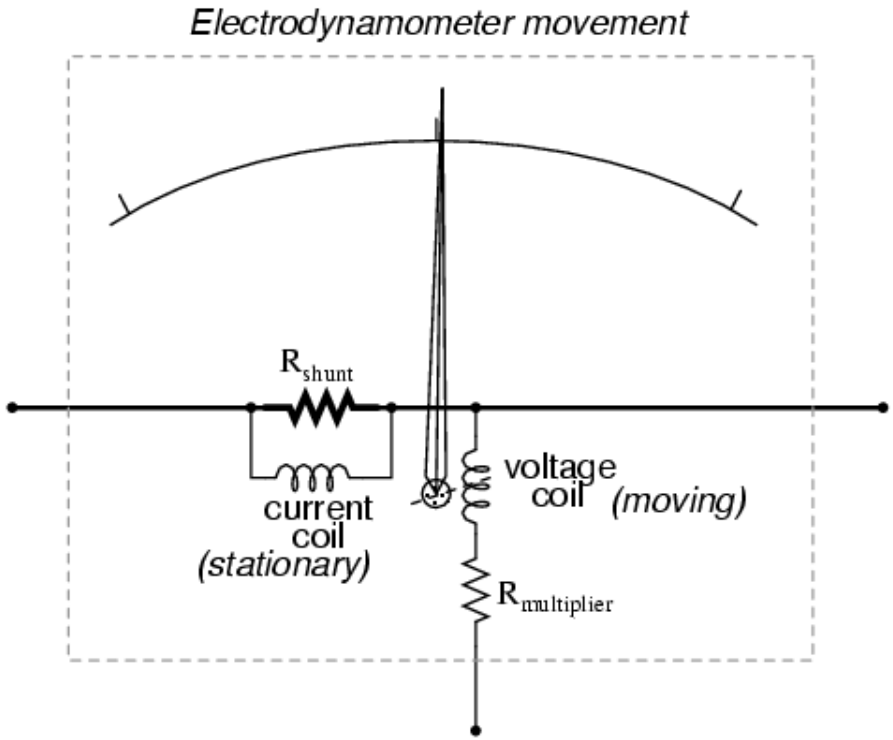
Moving Coil

- A single element instrument has one moving coil.
- The moving coil is wound either as a self-sustaining coil or else on a non-metallic former.
- A metallic former cannot be used as eddy current would be induced in it by the alternating field.
- Light but rigid construction is used for the moving coil.
- It should be noted that both fixed and moving coils are air cored.

Control

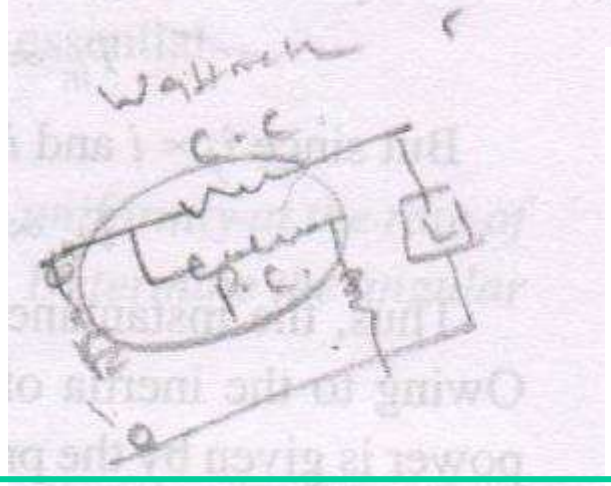
- The controlling torque is provided by two control springs.
- These springs act as leads to the moving coil.

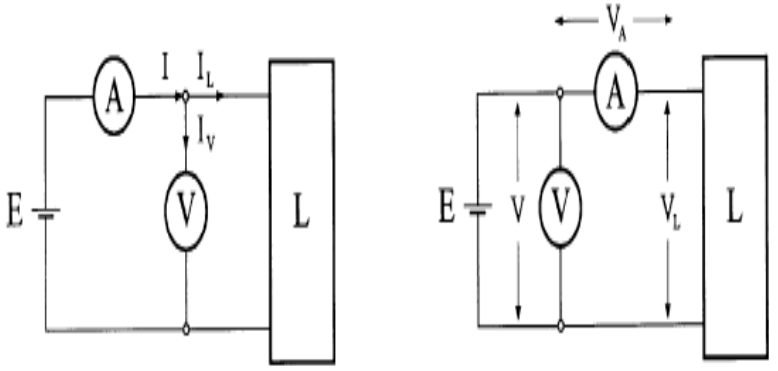
Electrodynamometer (Electrodynamics) Type Instruments



3. Electrodynamic Wattmeter The electrodynamic wattmeter consist of two fixed coils *'a'* and *'b'* placed symmetrical to each other and producing a uniform magnetic field. They are connected in series with the load and are called the Current Coils (CC). The two fixed coils can be connected in series or parallel to give two different current ratings. The current coils carry the full-load current or a fraction of full load current. Thus the current in the current coils is proportional to the load current. The moving coil *'c'*, in series with a high non inductive resistance R_v is connected across the supply. Thus the current flowing in the moving coil is proportional to, and practically in phase with the supply voltage. The moving coil is also called the voltage coil or Pressure Coil (PC). The voltage coil is carried on a pivoted spindle which carries the pointer, the pointer moved over a calibrated scale.

Two hair springs are used for providing the controlling torque and for leading current into and out of the moving coil. Damping is provided by air friction. Figure 2.20 shows the basic arrangement of a electrodynamic wattmeter.





(a) $P = I_L V_L$ (b)

a) Ammeter measures current which flow into the voltmeter and load

b) Voltmeter measures voltage drop across the ammeter in addition to that dropping across the load

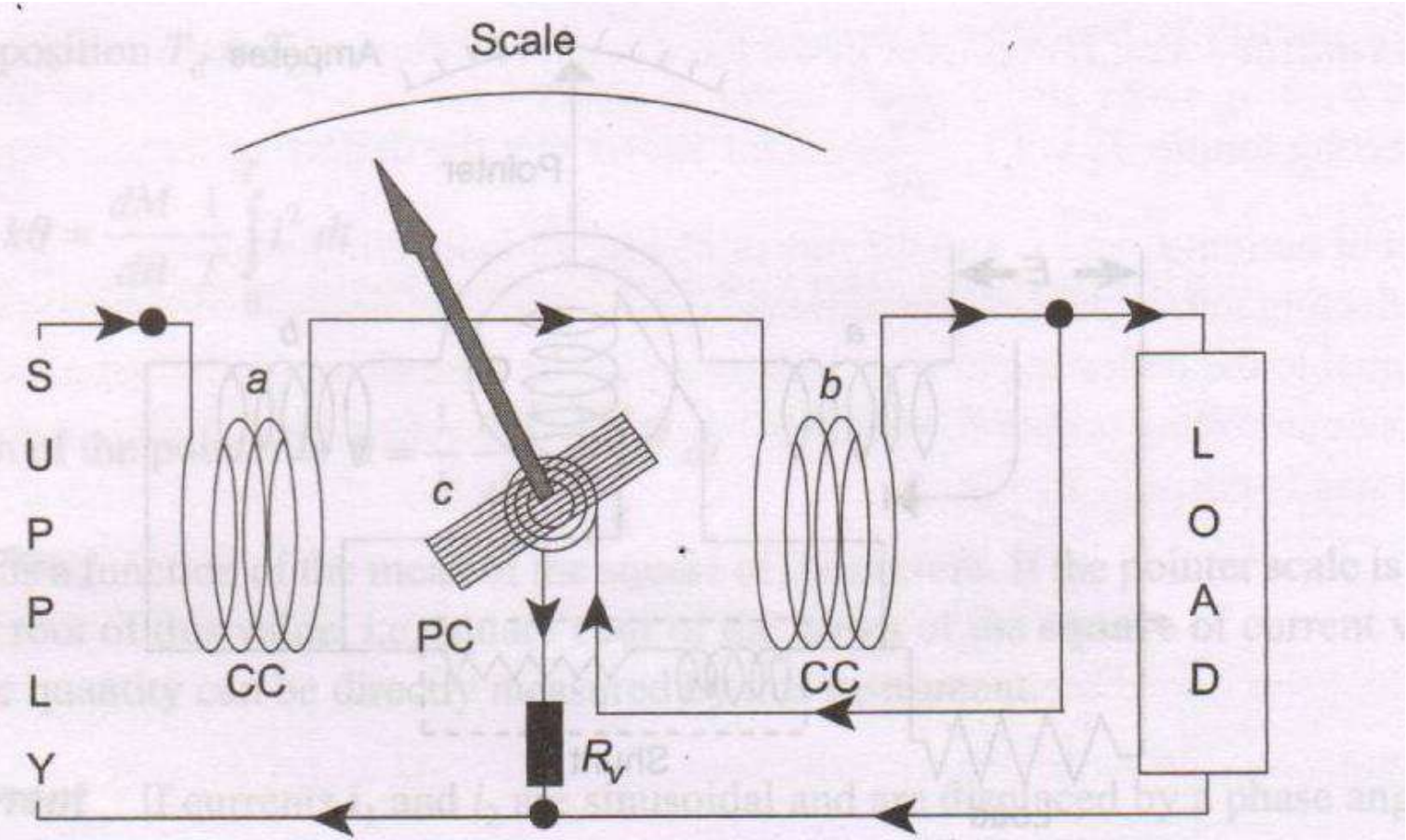


Figure 2.19 *Electrodynamic wattmeter*

4. Torque Equation

Let, i_f = current in the fixed coil
i_m = current in the moving coil
i = load current
v = load voltage
T_{in} = instantaneous value of the deflecting torque
p = instantaneous power

$$T_{in} \propto i_f i_m \tag{2.39}$$

But since $i_f \propto i$ and $i_m \propto v$

$$T_{in} \propto vi \propto p \tag{2.40}$$

Thus, the instantaneous value of the deflecting torque is proportional to the instantaneous power. Owing to the inertia of the moving system, the pointer reads the average power. In dc circuits, the power is given by the product of voltage and current, and hence the torque is directly proportional to the power. Thus, the instrument indicates the power.

For ac, the instrument indicates the average power. This can be proved as follows:

$$T_{in} \propto vi$$

Average deflecting torque $\propto$ average power

Let, $v = V_m \sin \theta$

$I = I_m \sin (\theta - \Phi)$

Average deflecting torque $\propto$ average value of $V_m \sin \theta \times I_m \sin (\theta - \Phi) \propto VI \cos \theta$

If T_d be the average torque, then

$$T_d \propto VI \cos \Phi \propto \text{true power} = kP \qquad (2.41)$$

where P is the true power and k is the constant.

For spring control $T_c = k_s \theta_1$

where T_c is the control torque, k_s is the spring constant and θ_1 is the angle of deflection of the pointer.

For steady deflection,

$$T_c = T_d$$

$$k_s \theta_1 = kP$$

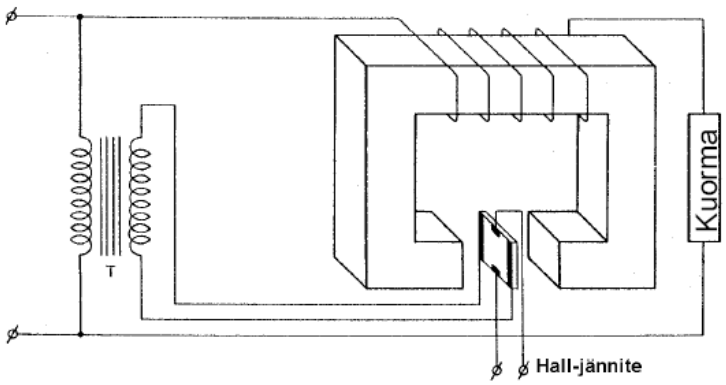
$$\theta_1 = \frac{k}{k_s} P$$

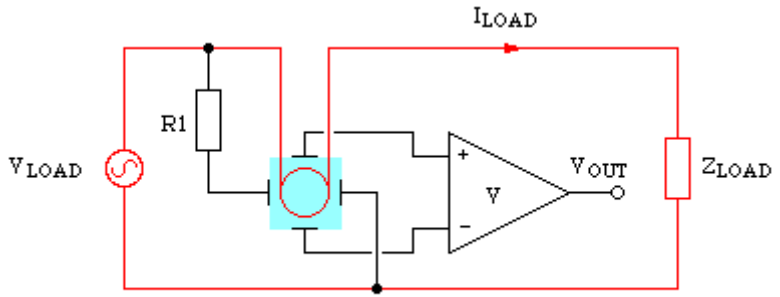
$$\theta_1 \propto P$$

Hence, in case of ac also the deflection is proportional to the true power in the circuit. The scale of the electrodynamometer wattmeter is therefore uniform.

Hall effect Wattmeter/ Hall power meter

- Coil generates magnetic field which is proportional to load current.
- The sensor excitation current passes through R1, and is proportional to the load voltage → Hall voltage is proportional to load power.
- Limitations: offset and linearity.





Circuit 9. Schematic wattmeter based on Hall effect sensor

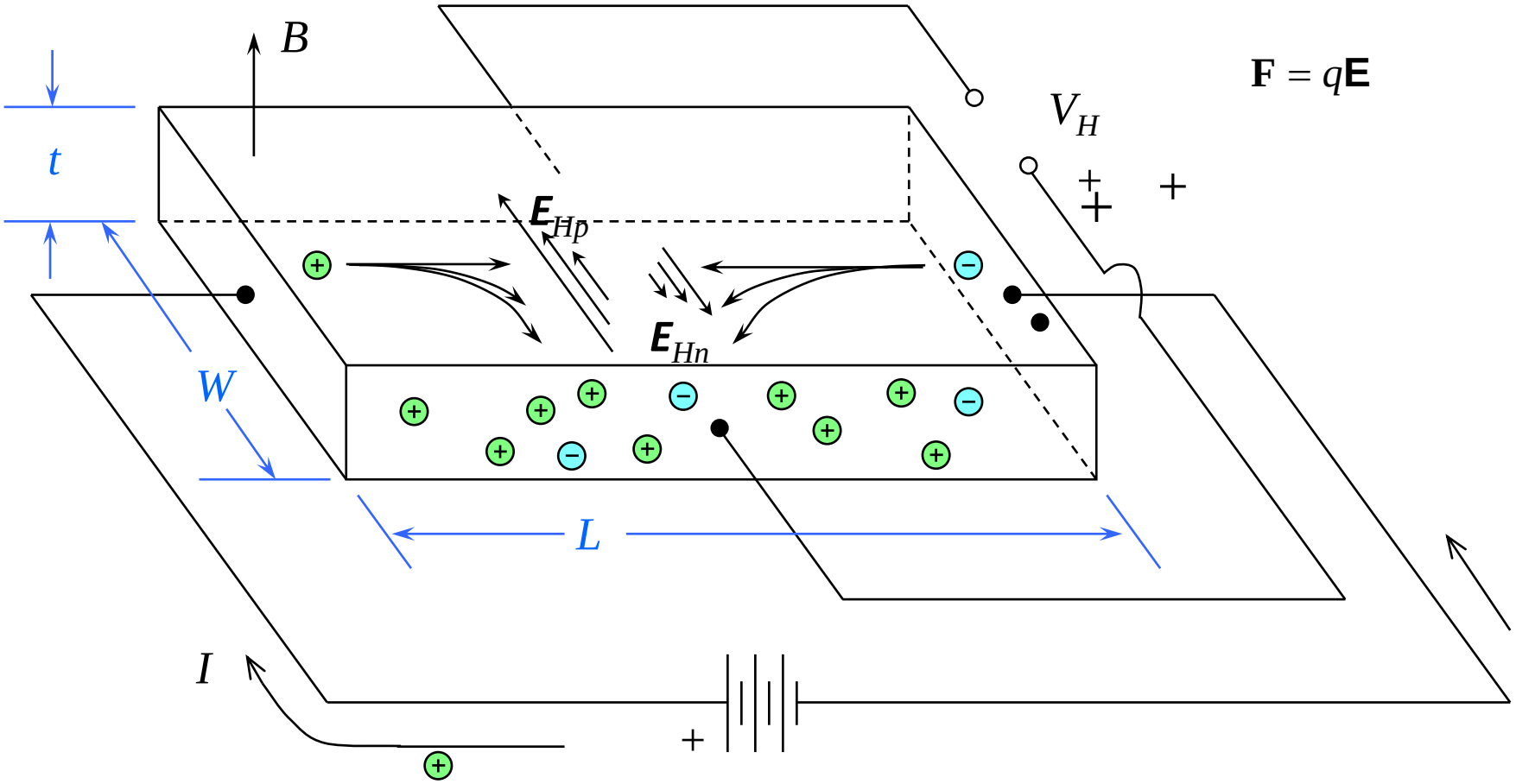
The Hall Effect

- When there is a Magnetic field in the presence of a conductor a voltage is induced due to electron and hole drift.

$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$

Hall Effect

$q = +q$ for holes
$= -q$ for electrons



$\mathbf{F} = q\mathbf{E}$

Hall effect Wattmeter/ Hall power meter

- $V_{hall} = -(I*B)/(d*n*e)$
- $R_{hall} = -1/(n*e)$

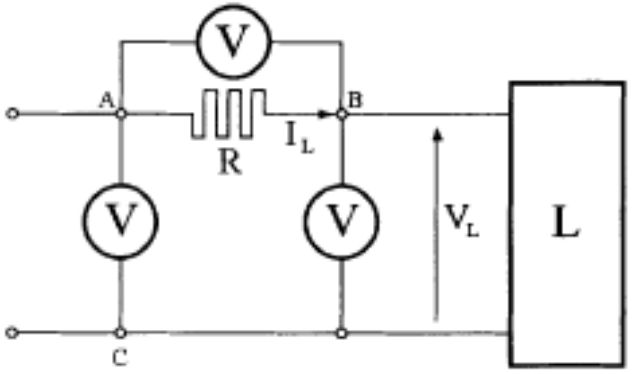
current through wire

- $B_{field} = Uo * Ip/(2*pi*r)$

- I= current
- B = Mag Flux Dens
- d = depth of plate
- e = electric charge
- j = current density
- n = charge carrier dens
- r = distance to center of wire
- Uo = 4*pi*10^-7

- Three-Voltmeter Method
  - Single-phase arrangements
  - Power in load can be measured using a non-inductive resistor and measuring the three voltage
  - Also, in DC circuits

$$P_L = \frac{V_{AC}^2 - V_{AB}^2 - V_{BC}^2}{2R}$$



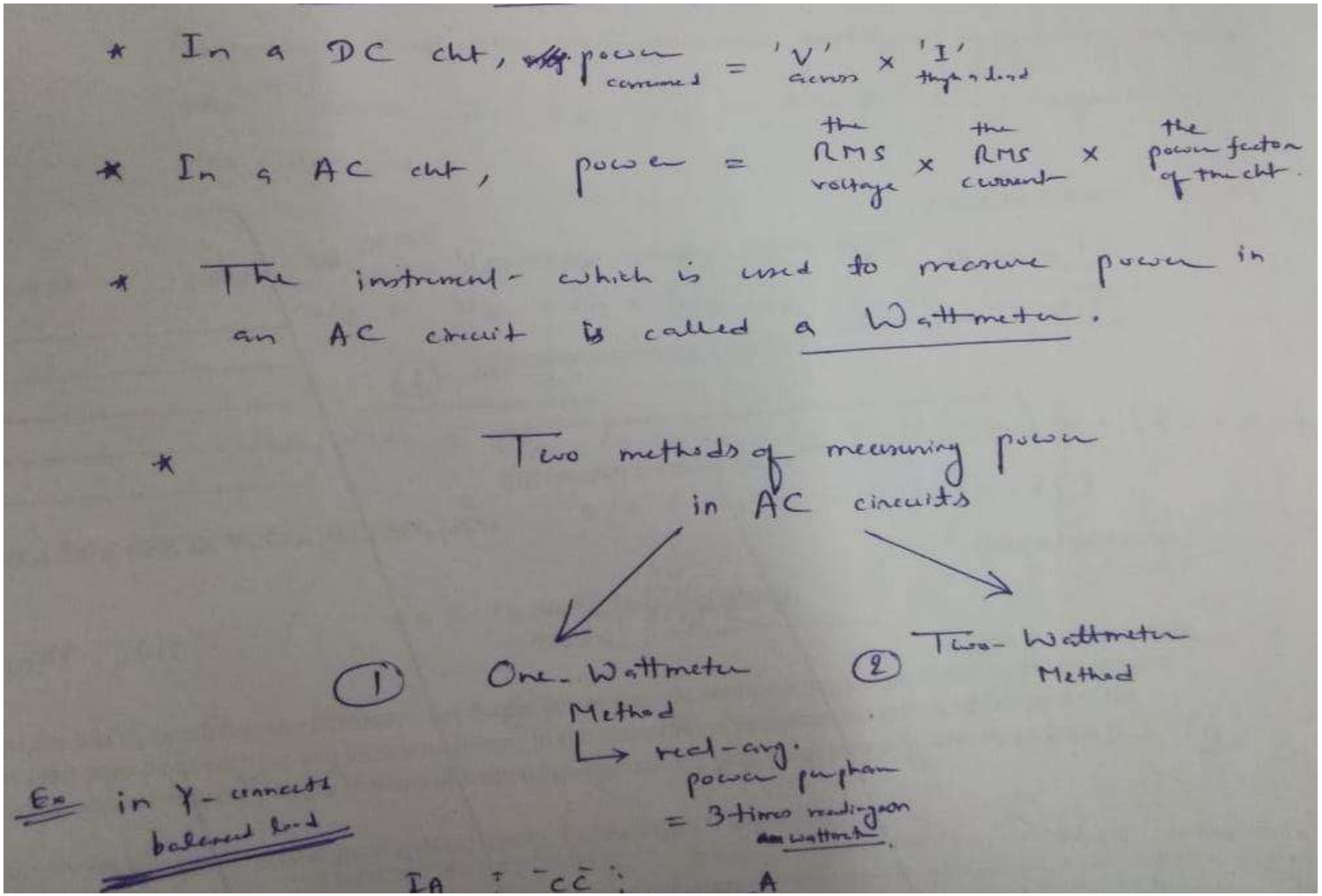
Low Frequency Power Measurements

- Polyphase Power Measurements
  - Three-phase systems are most commonly used in industrial applications
  - Energy and power generation and distribution
  - Real power for consumer
  - Reactive power also important due to loading

Low Frequency Power Measurements

- Four different cases that affects to the measurement arrangements:
  1. Symmetrical load with neutral conductor
  2. Symmetrical load without neutral conductor
  3. Unsymmetrical load with neutral conductor
  4. Unsymmetrical load without neutral conductor

Measurement of 3-Phase Power

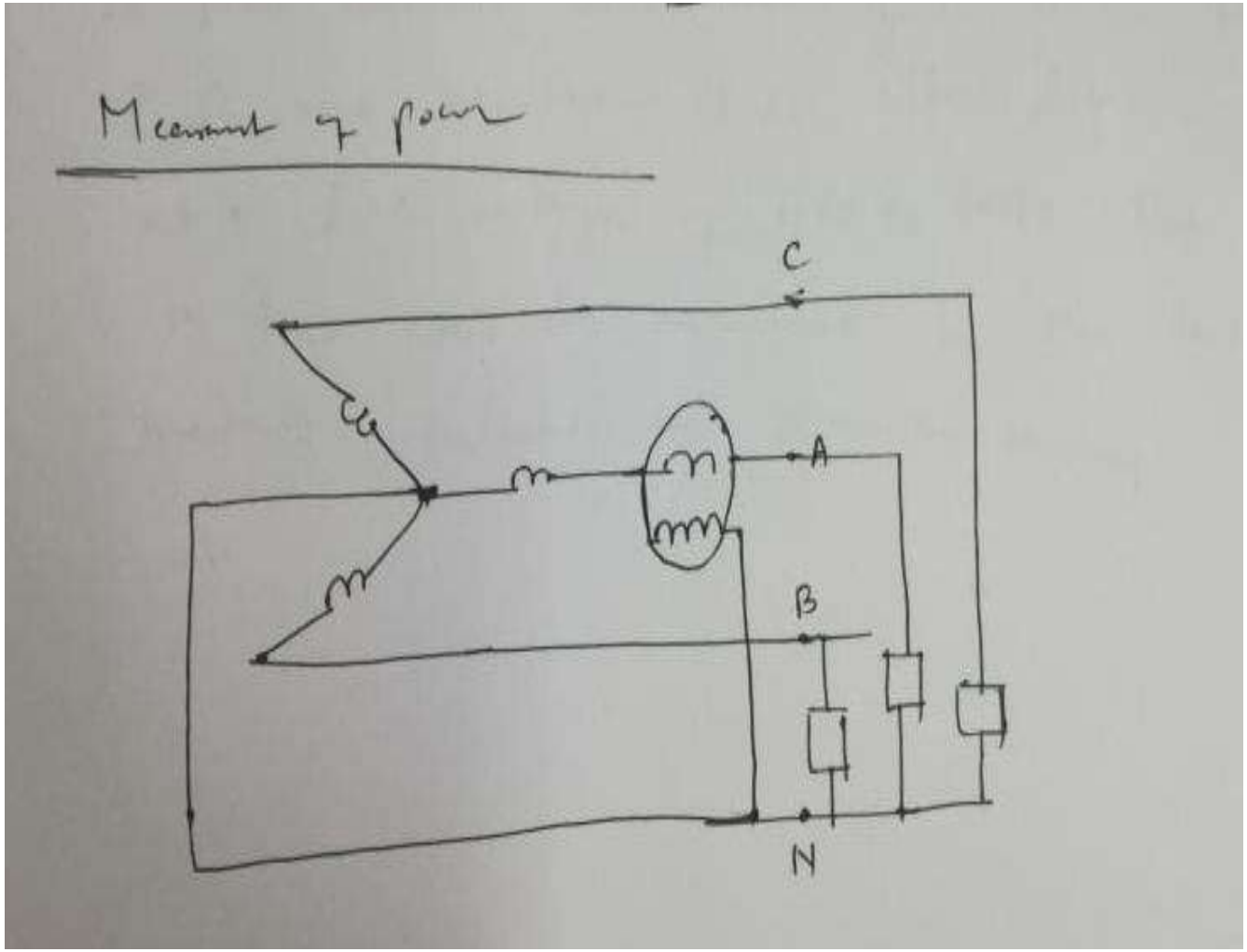


https://www.youtube.com/channel/UC0ISZ4dMZcIBeIzjZVRZhJw/videos

Low Frequency Power Measurements

- Measurements can be done by
  - One-wattmeter arrangements
  - Two-wattmeter arrangements
  - Three-wattmeter arrangements

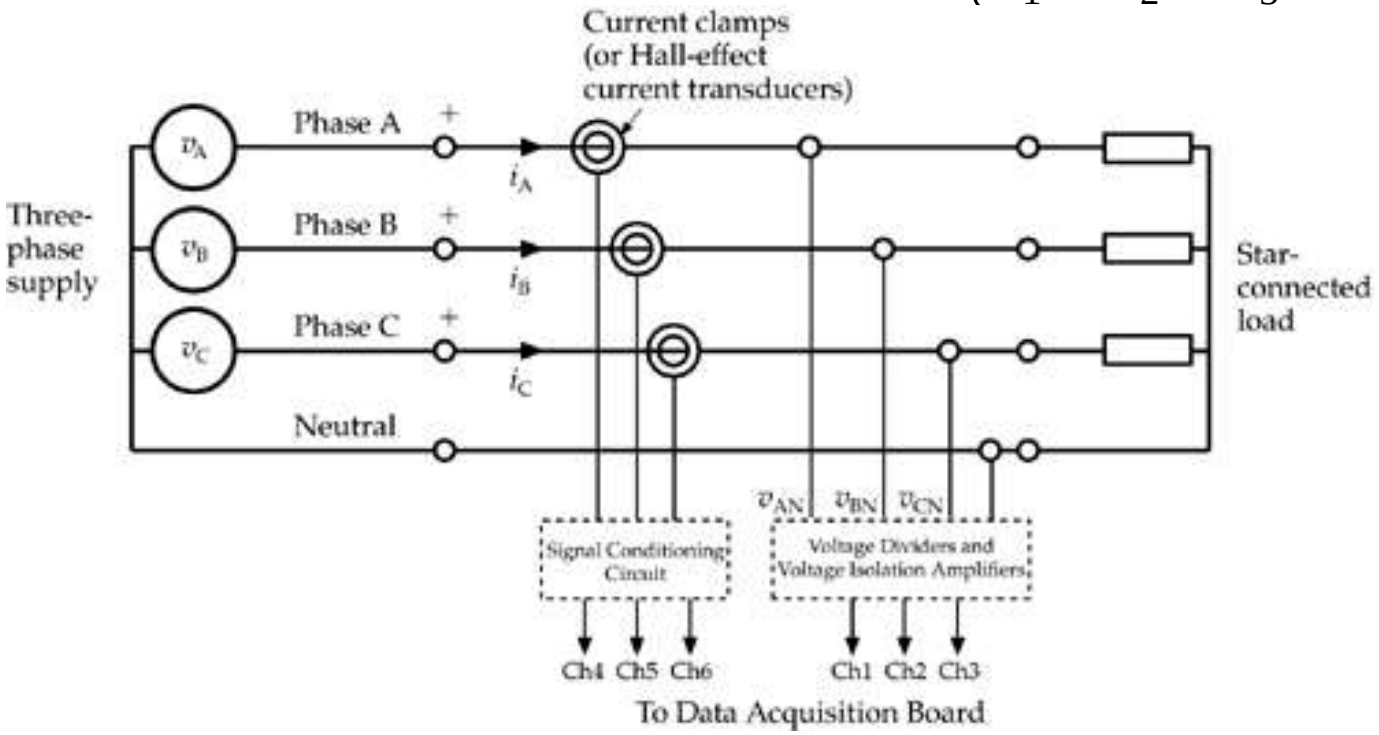
Measurement of Power



Symmetrical and Balanced systems

- The supply system is symmetrical, and the three-phase load is balanced when phase currents and voltages are equal
- Normal situation

$$\begin{cases} V_1 = V_2 = V_3 \\ I_1 = I_2 = I_3 \end{cases}$$



Symmetrical load with neutral conductor

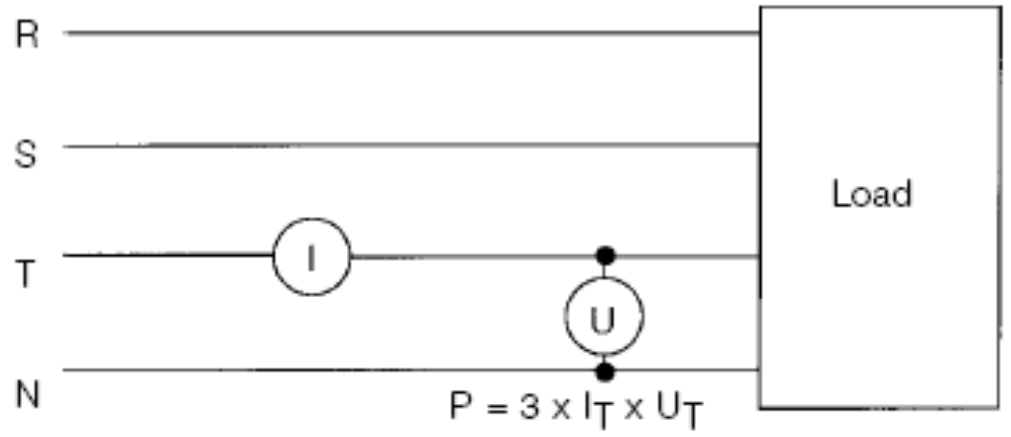
Symmetrical load with neutral conductor

- Number of wattmeter (voltage/current meter) is (*n*-1) where *n* is number of conductors.
- If *n=3,* only one wattmeter are compulsory.
- Power factor is measured using power factor meter.

$$\begin{cases} S = V_1 I_1 + V_2 I_2 + V_3 I_3 \\ P = S\cos\delta \\ Q = S\sin\delta \end{cases}$$

One Wattmeter Method

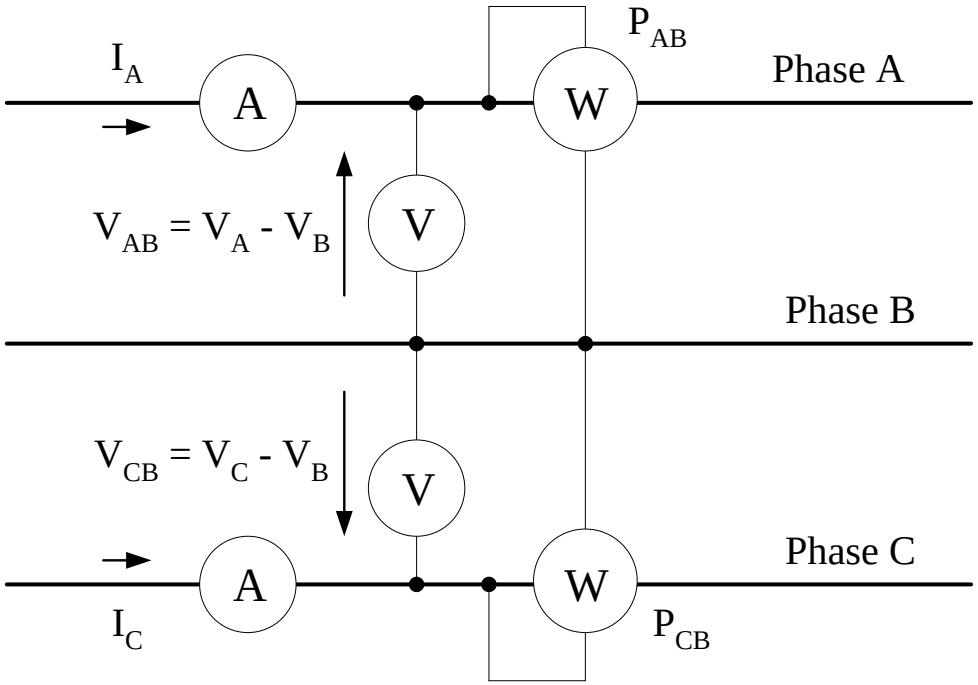
- One wattmeter arrangements for real and reactive power measurements



$$P = 3U_T I_T \cos\delta$$

Symmetrical load without neutral conductor

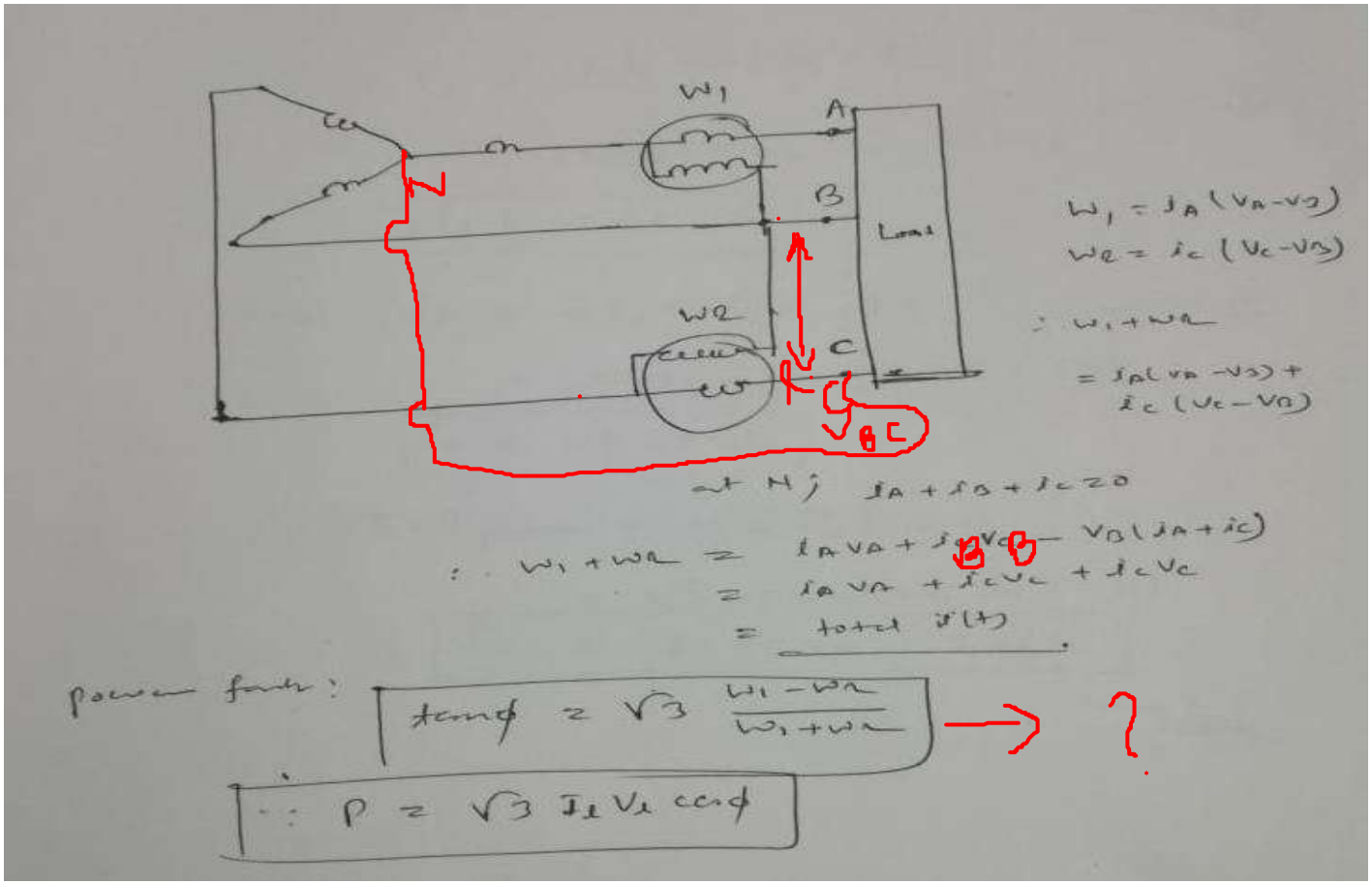
- Active and reactive power can be measured with two power meter (in three-wire system), case of symmetrical load and without neutral conductor (motors) based on Aron's theorem.
- Possible to use also in case of unsymmetrical load.
- If power factor is less than 0.5, then three wattmeter arrangement.



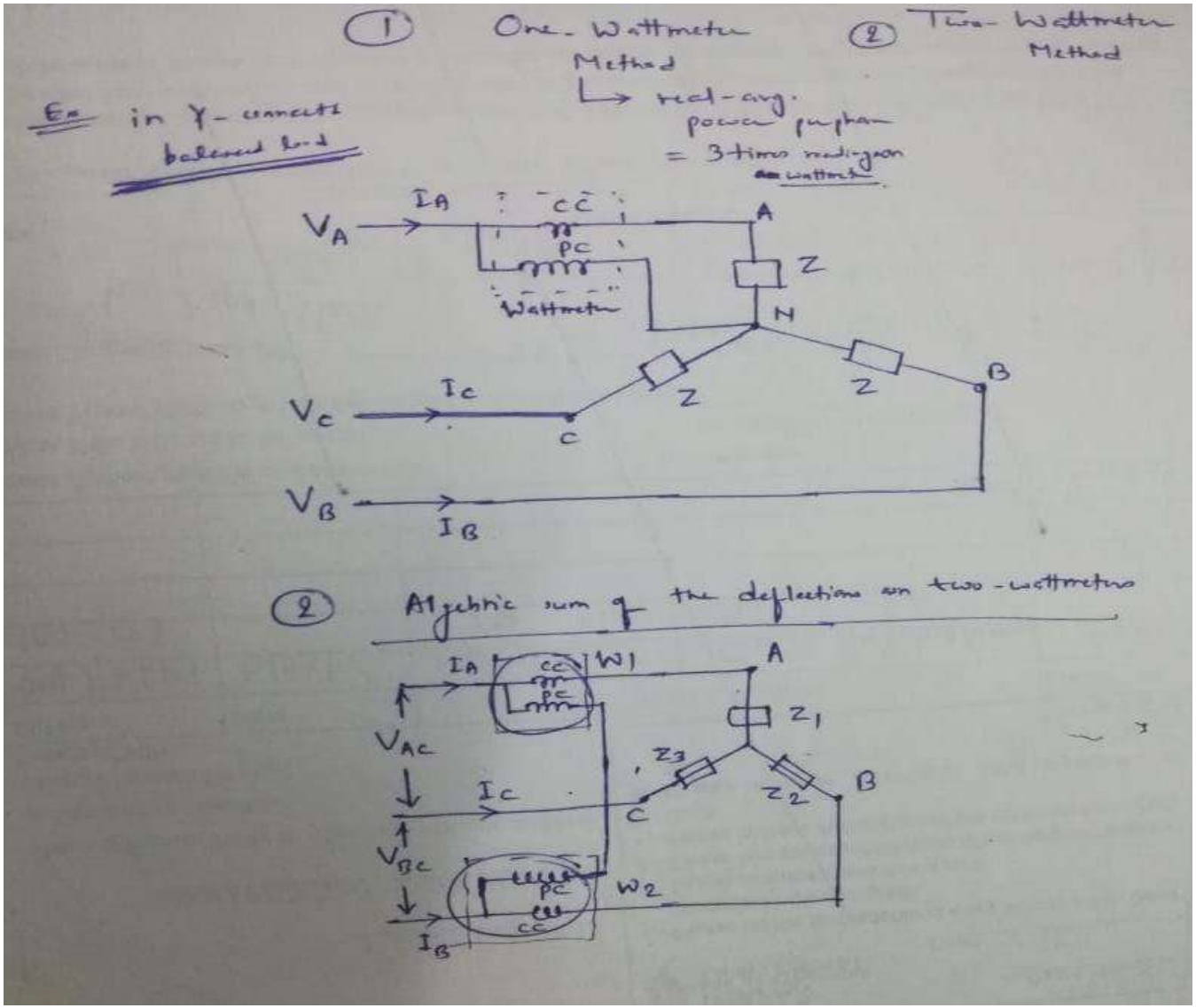
$$P = P_{AB} + P_{CB}$$

$$Q = \sqrt{3} * \left(P_{AB} + P_{CD}\right)$$

Two Wattmeter Method



Measurement of 3-Phase Power



Measurement of Unbalanced 3-Phase Load

Assuming that the instantaneous voltages appearing across the loads Z_1, Z_2, Z_3 at time 't' are, respectively, v_A, v_B, and v_C.

$$\therefore \quad W_1 = V_{AC} \cdot i_A = (V_A - V_C) \cdot i_A \qquad \text{---(1)}$$

$$W_2 = V_{BC} \cdot i_B = (V_B - V_C) \cdot i_B \qquad \text{---(2)}$$

(1) + (2)

$$W_1 + W_2 = V_{AC} \cdot i_A + V_{BC} \cdot i_B = (V_A - V_C) i_A + (V_B - V_C) \cdot i$$

$$= V_A i_A + V_B i_B - V_C (i_A + i_B) \qquad \text{---(3)}$$

$$\therefore \quad i_A + i_B + i_C = i_N = 0$$

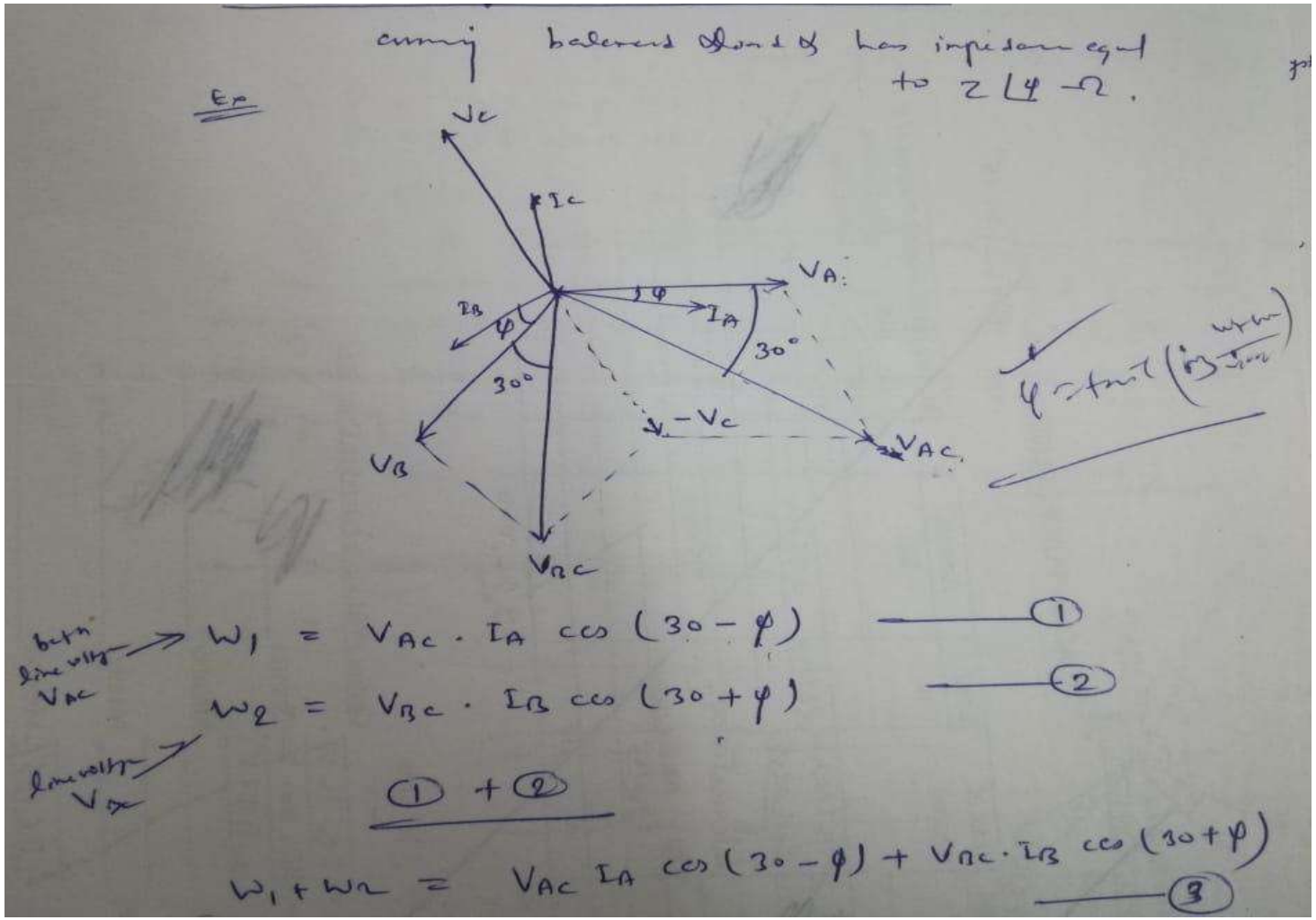
$$\therefore \quad \text{From eq}^n \text{ (3)};$$

$$W_1 + W_2 = V_A i_A + V_B i_B + V_C i_C \qquad \text{---(4)}$$

Eq^n (4) shows that the two-wattmeter method measures power in a 3-ϕ unbalanced load.

* the same result can be obtained for Δ-connected load as well.

Measurement of Balanced 3-Phase Load



- Current amplitudes are different, and their relative phase is not equal 120°
- Usually it is caused by some fault (short circuit)
- Two or three wattmeter arrangements (depends on neutral point)

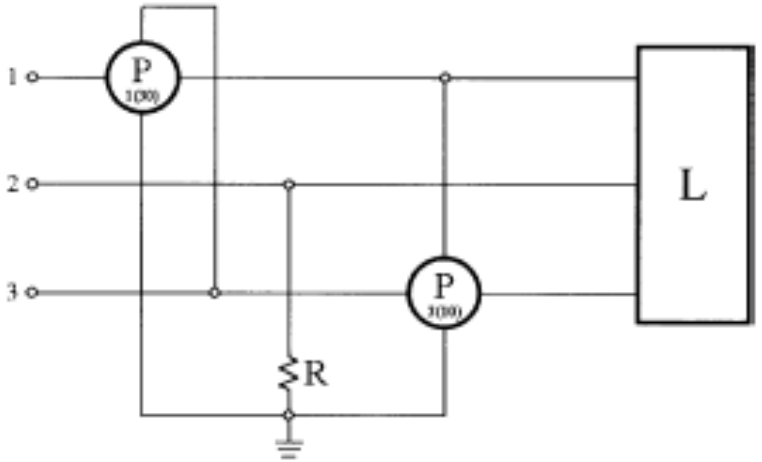
❖ Four possible arrangements:

- Three-wattmeter arrangement
- Two-wattmeter arrangement
- Barbagelata arrangement
- Righi arrangement

Two-wattmeter arrangement for measurement of reactive power

- Measurements arrangements for reactive power measurements

$$Q = \sqrt{3}\left[-P_{1(30)} + P_{3(10)}\right]$$



- where

$$P_{1(30)} = P_{10} - P_{13}$$

Measurement of Reactive Power

real power – P, reactive power – Q for a 1–φ system.

$P = VI\cos\varphi$ W

$Q = VI\sin\varphi$ VAR

$\because \sin\varphi = \cos(90-\varphi)$,

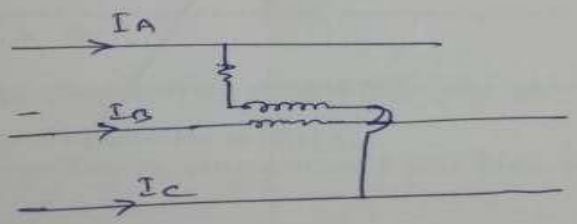
$\therefore$ A wattmeter may be used for measuring Q if the current coil (cc) carries the current I and the voltage applied to the pressure/potential coil (pc), is such that its phase displacement from the actual voltage of the circuit is 90°.

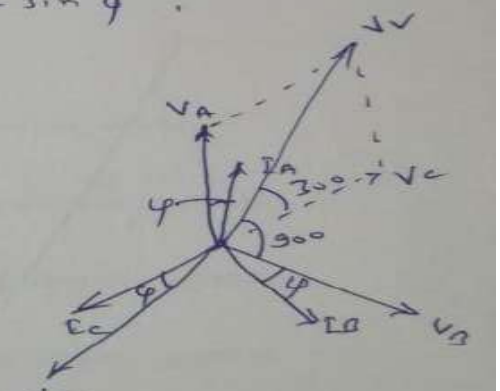
$\therefore$ the wattmeter will read $VI\cos(90-\varphi)$

i.e. $VI\sin\varphi$.

In case of 3 φ system,

In 3–φ;





since $V_A = V_B = V_C = V$ (line voltage)

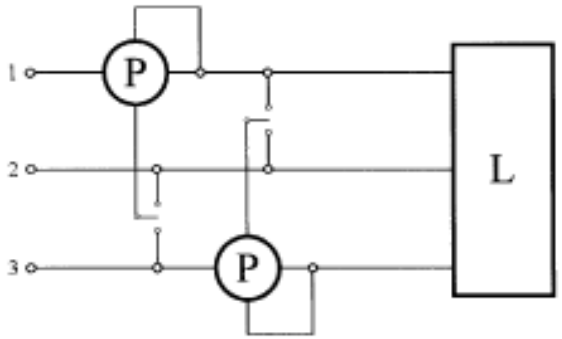
$I = I_A = I_B = I_C$ (line current)

$V_L I_B \cos(90+\varphi) = \sqrt{3}\, VI\cos(90+\varphi)$

$= -\sqrt{3}\, VI\sin\varphi = -W_R$

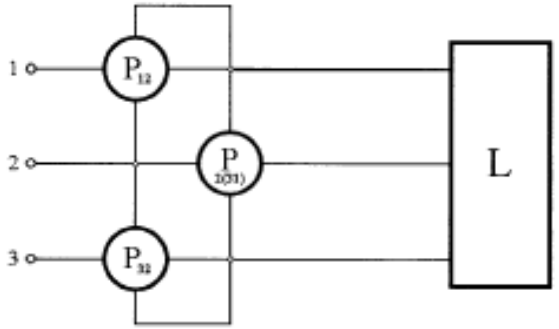
$\therefore Q_{3-\varphi} = 3VI\sin\varphi = -\sqrt{3}\, W_R$

Barbagelata arrangements



$$\begin{cases} P = P_{12} + P_{32} \\ Q = \dfrac{1}{\sqrt{3}}\left[2\left(P_{13} - P_{31}\right) + P_{32} - P_{12}\right] \end{cases}$$

Righi arrangements



$$Q = \frac{1}{\sqrt{3}}\left[P_{32} - P_{12} + 2P_{2(31)}\right]$$

Low Power Factor Wattmeter

❖ Difference between Electrodynamometer Wattmeter and Low Power Factor Wattmeter

✓ Electrodynamometer wattmeter and Low Power Factor (LPF) wattmeter are mostly similar in construction and operation, except for the following modifications are carried out in the electrodynamometer wattmeter to convert it into a LPF wattmeter:

- Pressure coil resistance is kept low to increase the torque.
- Compensating coil is used to compensate the Pressure coil current.
- Capacitor is connected across the pressure coil to reduce the error due to pressure coil inductance.
- Control torque is made very less for high deflection.

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- Control torque is made very less for high deflection.

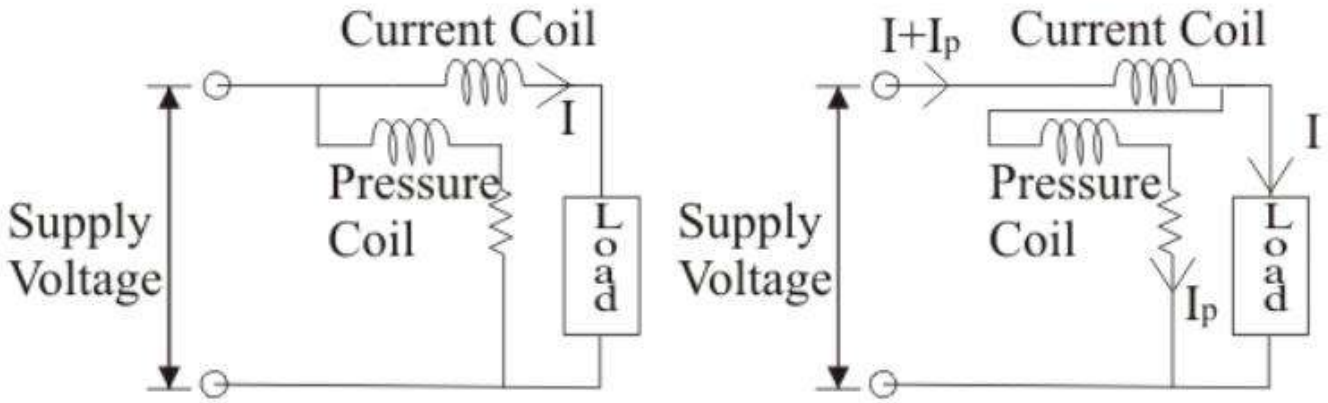
Low Power Factor Wattmeter

- Why a LPF Wattmeter is needed?
  - ✓ the usage of ordinary electrodynamometer wattmeter to measure power factor of a low pf load gives inaccurate results.

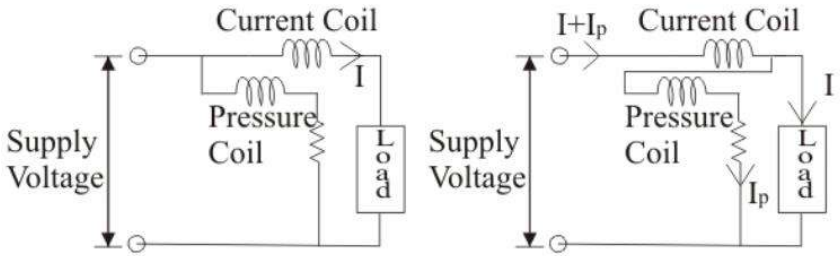
  - The value of deflecting torque is very low even though we fully excite the current and pressure coils.
  - Errors due pressure coil inductance.

Low Power Factor Wattmeter

- Compensating the pressure coil current:



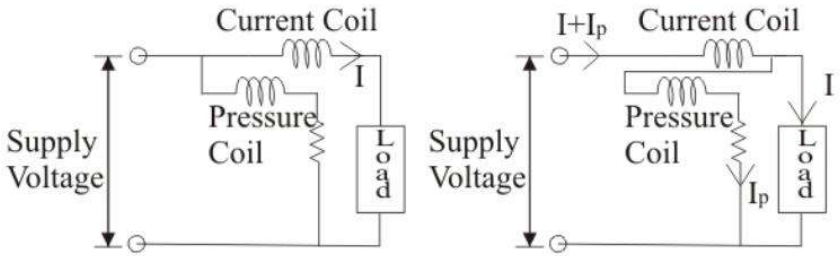
❖ Compensating the pressure coil current:



- In the first category, both the ends of the pressure coil is connected to supply side, that is, current coil is in series with the load. The supply voltage is equal to the voltage across the pressure coil. Therefore, in this case, power measured by the wattmeter is equal to the power loss in the load plus power loss in the current coil.

- In the second category, the current coil is not in series with the load and the voltage across the pressure coil is not equal to the applied voltage. The voltage across pressure coil is equal to the voltage across the load. Therefore, in this case, power measured by the wattmeter is equal to the power loss in the load plus the power loss in the pressure coil.

❖ Compensating the pressure coil current:

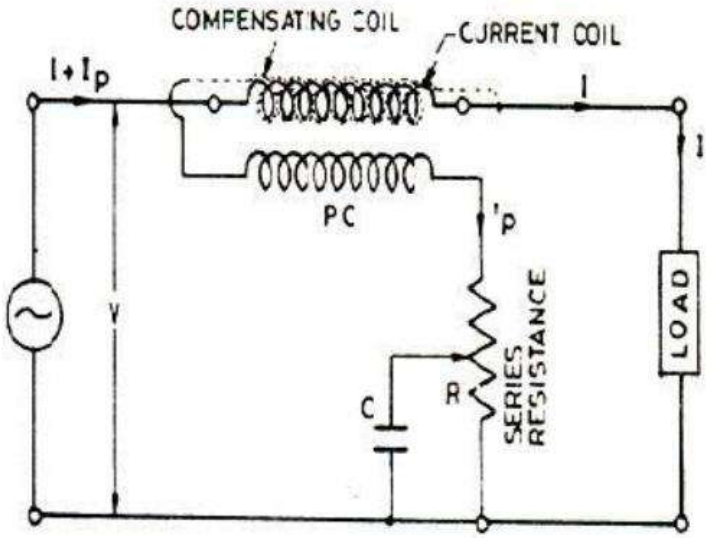


Thus, it is absolutely necessary to compensate for the pressure coil current in a LPF wattmeter.

- The compensating coil is connected in series with the pressure coil circuit and is made nearly identical to the current coil. The current coil and the compensating coil carry currents of (I + Ip) and Ip, respectively, and they produce fields corresponding to these currents. The compensating coil is so connected that it opposes the field of the current coil. Thus, the resultant field is due to current I only.
- Hence, the error due to pressure coil current flowing in current coil is neutralized.

Low Power Factor Wattmeter

- Compensating the pressure coil current:



- Compensation for Inductance of Pressure Coil:
  - The error caused by pressure coil inductance is
  - Error= V I sin(Φ) tan(β)

- Small Control Torque:
  - LPF wattmeter are designed to have a small control torque so that they give full scale deflections.

High-frequency power measurements

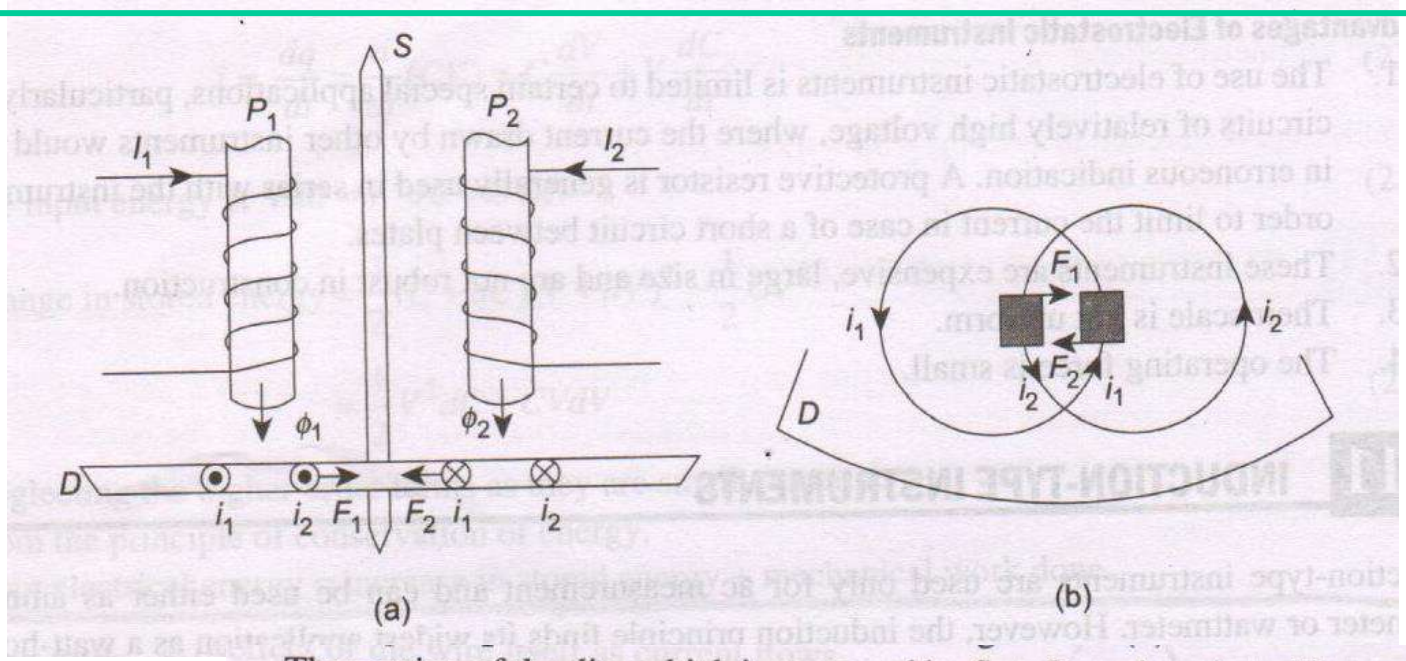
- Radio (< 300 MHz) or microwave (> 1 GHz) frequencies
- Measurement devices are classified by absorption type and transmitted or throughline type
- Based on thermistors, thermocouples, diodes or radiation sensors
- Should be calibrated very carefully due to low time-duration.

Induction Type Instruments

Induction-type instruments are used only for ac measurement and can be used either as ammeter, voltmeter or wattmeter. However, the induction principle finds its widest application as a watt-hour or energy meter (for details, refer Chapter 8). In such instruments, the deflecting torque is produced due to the reaction between the flux of an ac magnet and the eddy currents induced by another flux.

2.11.1 Principle of Operation

The operations of induction-type instruments depend on the production of torque due to the interaction between a flux Φ_1 (whose magnitude depends on the current or voltage to be measured) and eddy current induced in a metal disc or drum by another flux Φ_2 (whose magnitude also depends on the current or voltage to be measured). Since the magnitude of eddy current also depends on the flux producing them, the instantaneous value of the torque is proportional to the square of current or voltage under measurement and the value of mean torque is proportional to the mean square value of this current or voltage.



The portion of the disc which is traversed by flux Φ_1 and carries eddy currents i_2 experiences a force F_1 along the direction as indicated. As $F = Bil$, force $F_1 \propto \Phi_1 i_2$. Similarly, the portion of the disc lying under flux Φ_2 and carrying eddy current i_1 experiences a force $F_2 \propto \Phi_2 i_1$.

$$\therefore \quad F_1 \propto \varphi_1 i_2 = k\varphi_1 i_2 \tag{2.48}$$

$$F_2 \propto \varphi_2 i_1 = k\varphi_2 i_1 \tag{2.49}$$

It is assumed that the constant k is the same in both the cases due to the symmetrical position of P_1 and P_2 with respect to the disc.

If r be the effective radius at which these forces acts, then net instantaneous torque T acting on the disc being equal to the different of the two torques, it is given by

$$T = r(k\varphi_1 i_2 - k\varphi_2 i_1) = k_1(\varphi_1 i_2 - \varphi_2 i_1) \tag{2.50}$$

Let the alternating flux φ_1 be given by $\varphi_1 = \varphi_{1m} \sin \omega t$. The flux φ_2 which is assumed to lag φ_1 by an angle α radian is given by $\varphi_2 = \varphi_{2m} \sin(\omega t - \alpha)$

Induced emf $e_1 = \dfrac{d\varphi_1}{dt} = \dfrac{d}{dt}(\varphi_{1m} \sin \omega t) = \omega \varphi_{1m} \cos \omega t$

Assuming the eddy current path to be purely resistive and of value R, then the value of eddy current is

$$i_1 = \frac{e_1}{R} = \frac{\omega \varphi_{1m}}{R} \cos \omega t$$

Similarly, $e_2 = \omega \varphi_{2m} \cos(\omega t - \alpha)$ and $i_2 = \dfrac{e_2}{R} = \dfrac{\omega \varphi 2m}{R} \cos(\omega t - \alpha)$

Substituting these values of i_1 and i_2 in Eq. (2.48), we get

$$T = \frac{k_1\omega}{R}\left[\varphi_{1m}\sin\omega t\cdot\varphi_{2m}\cos(\omega t-\alpha)-\varphi_{2m}\sin(\omega t-\alpha)\cdot\varphi_{1m}\cos\omega t\right]$$

$$= \frac{k_1\omega}{R}\varphi_{1m}\varphi_{2m}\left[\sin\omega t\cdot\cos(\omega t-\alpha)-\sin(\omega t-\alpha)\cdot\cos\omega t\right]$$

$$= \frac{k_1\omega}{R}\varphi_{1m}\varphi_{2m}\sin\alpha = k_2\omega\varphi_{1m}\varphi_{2m}\sin\alpha \quad \left[\text{putting } \frac{k_1}{R} = k_2\right] \tag{2.51}$$

The following is observed:

1. If $\alpha = 0$, i.e., if two fluxes are in phase, then net torque is zero. If, on the other hand, $\alpha = 90°$, the net torque is maximum for a given values of φ_{1m} and φ_{2m}.
2. The net torque is such a direction as to rotate the disc from the pole with leading flux, towards the pole with lagging flux.
3. Since the expression for torque does not involve t, it is independent of time, i.e., it has a steady value at all times.
4. The torque T is inversely proportional to R; the resistance of the eddy current path. Hence, it is made of copper or more often, of aluminium.

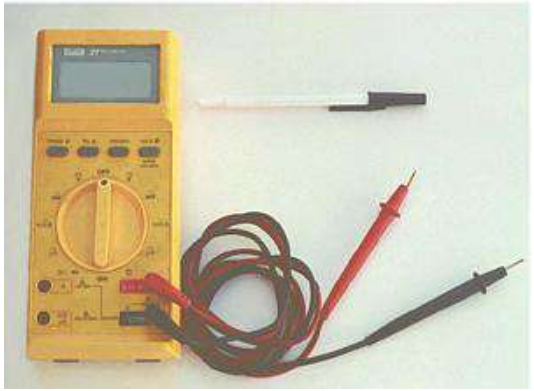
Electromechanical Indicating Instruments

- To familiarize the d'Arsonval meter movement, how it is used in ammeters, voltmeters, and ohmmeters, some of its limitations, as well as some of its applications.

Introduction

Meter: Any device built to accurately detect & display an electrical quantity in a form readable by a human being to **accurately measure** the basic quantities of voltage, current, and resistance.

Readable form

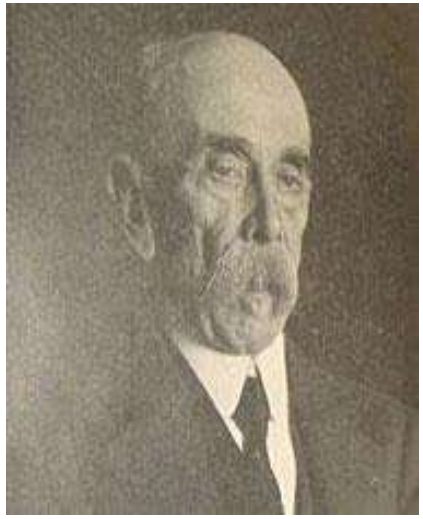


- Visual
- Motion of pointer on a scale
- Series of light (digital)

The d'Arsonval Meter

Hans Oersted (1777-1851)

Danish physicist who discovered the relationship between current and magnetism – from the deflection of a compass needle



Jacques d'Arsonval (1851-1940)

French physiologist who discovered the moving-coil galvanometer – from muscle contractions in frogs using a telephone, which operates on an extremely feeble currents similar to animal electricity

The d'Arsonval Meter

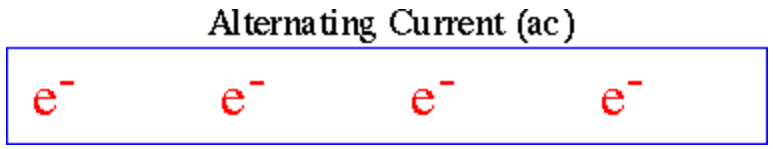
- In 1880s, two French inventors: Jacques d'Arsonval and Marcel Deprez patented the moving-coil galvanometer.

Jacques d'Arsonval
(1851 – 1940)

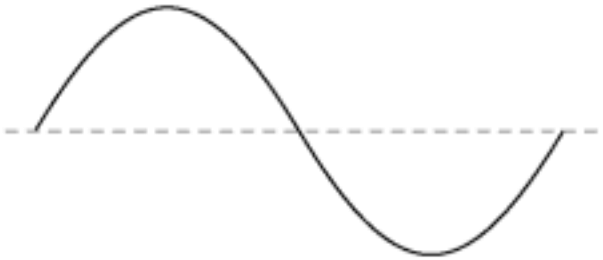
Deprez-d'Arsonval Galvanometer

Marcel Deprez
(1843 – 1918)

Alternating Current Waveform

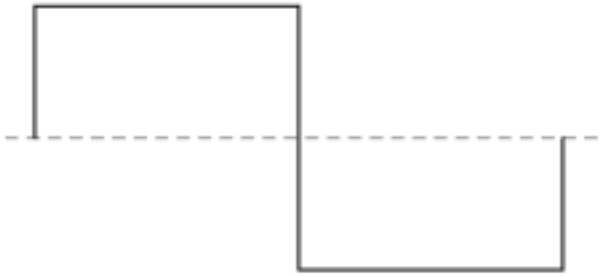


Sinusoidal wave



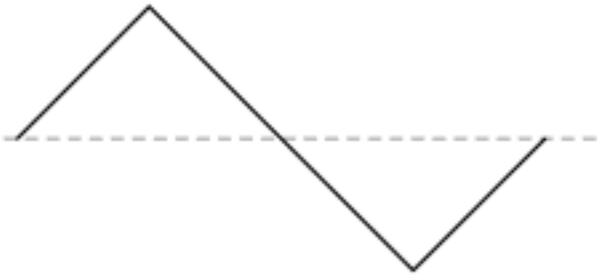
RMS = 0.707 (Peak)
AVG = 0.637 (Peak)
P-P = 2 (Peak)

Square wave



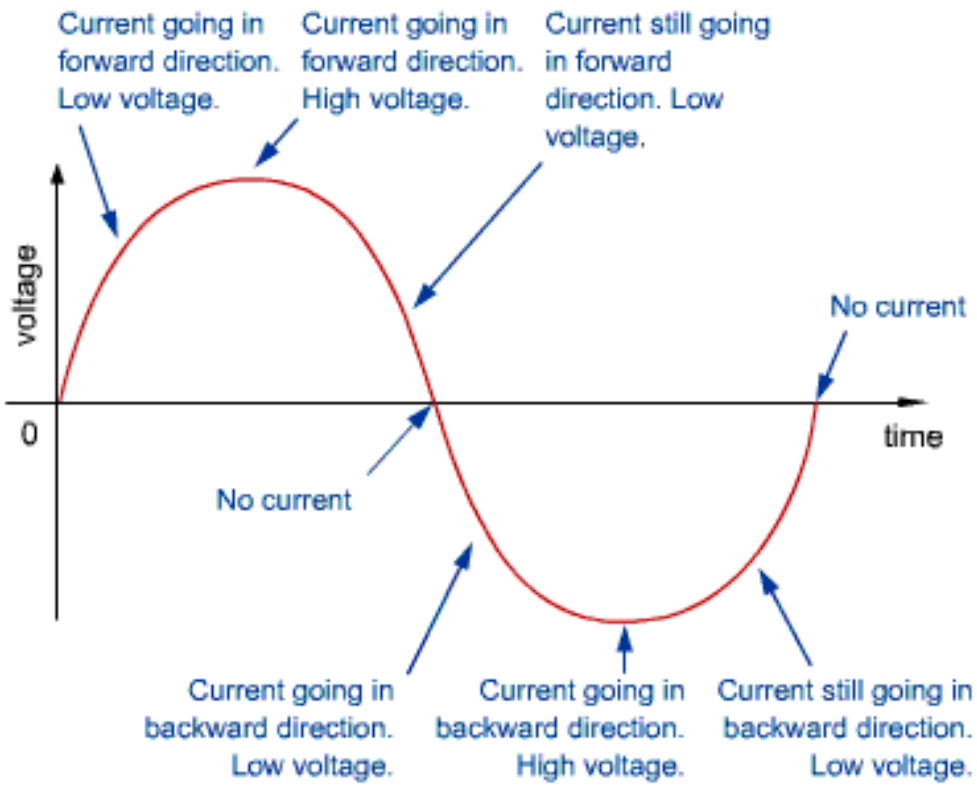
RMS = Peak
AVG = Peak
P-P = 2 (Peak)

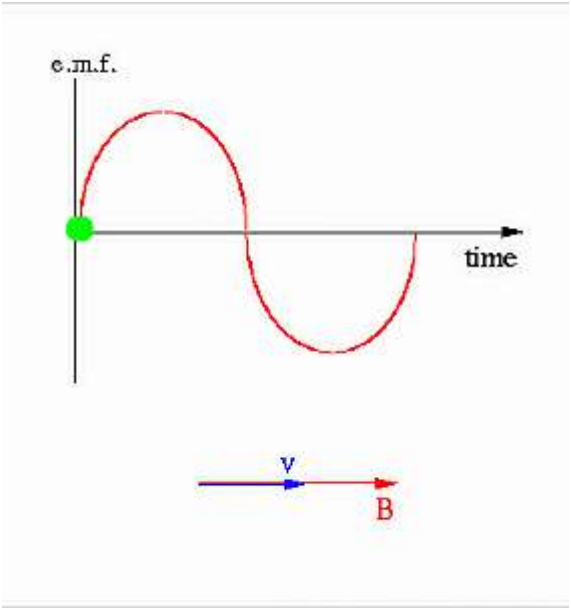
Triangle wave



RMS = 0.577 (Peak)
AVG = 0.5 (Peak)
P-P = 2 (Peak)

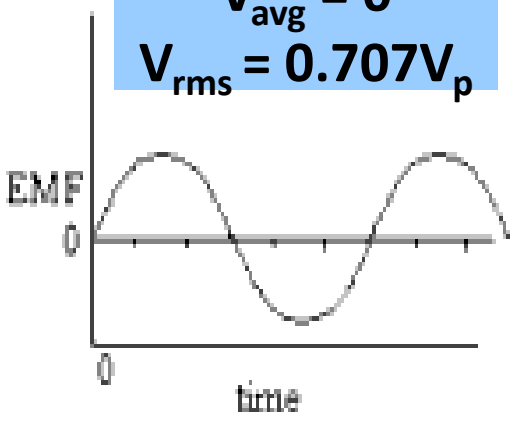
Alternating Current Waveform





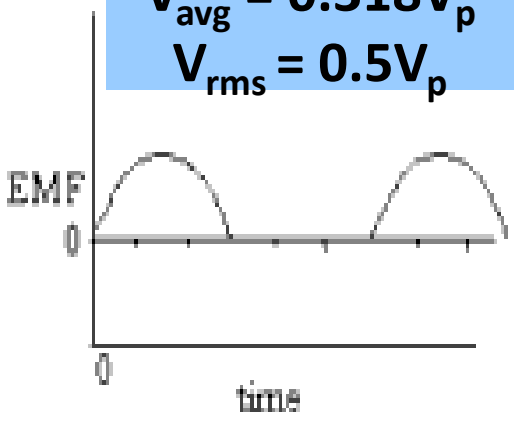
E_{rms}= E(root mean square), $E_{p\text{-}p}$= E peak-peak, E_p= E peak

$V_{avg} = 0$
$V_{rms} = 0.707V_p$



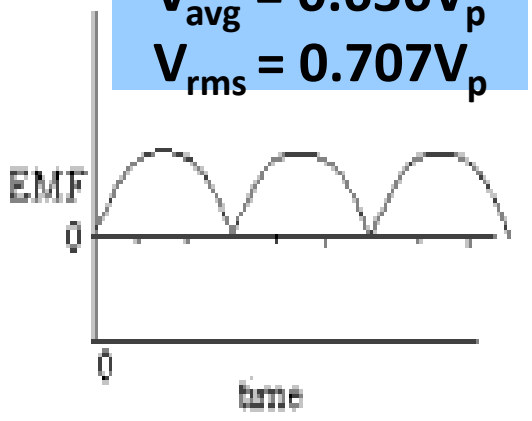
Simple single phase AC

$V_{avg} = 0.318V_p$
$V_{rms} = 0.5V_p$

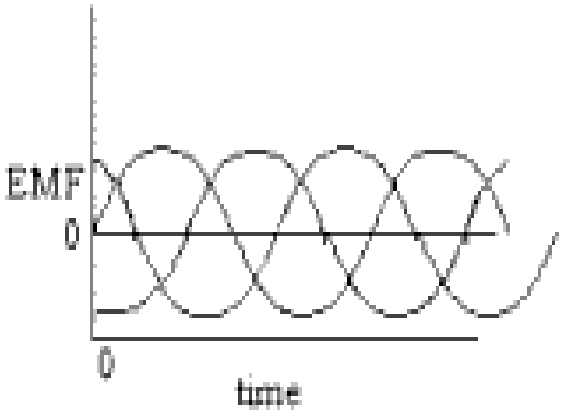


Single phase half wave rectified AC

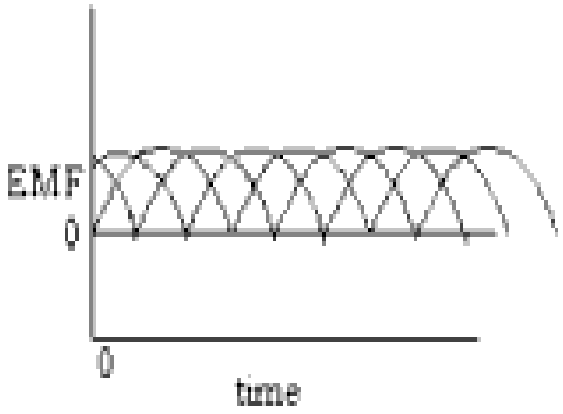
$V_{avg} = 0.636V_p$
$V_{rms} = 0.707V_p$



Single phase full wave rectified AC

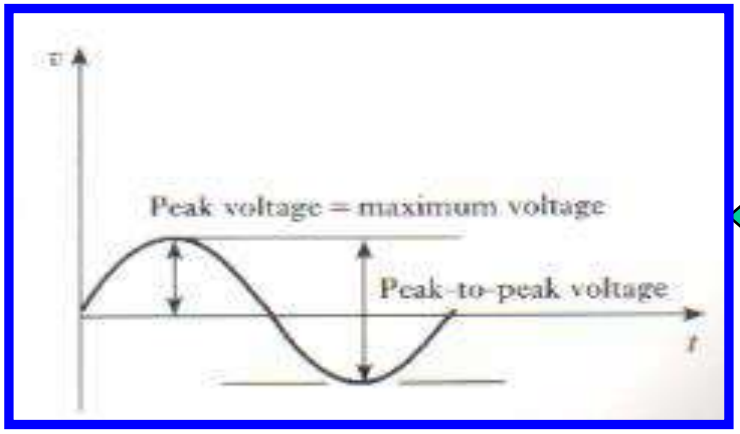


Three phase AC



Three phase full wave rectified AC

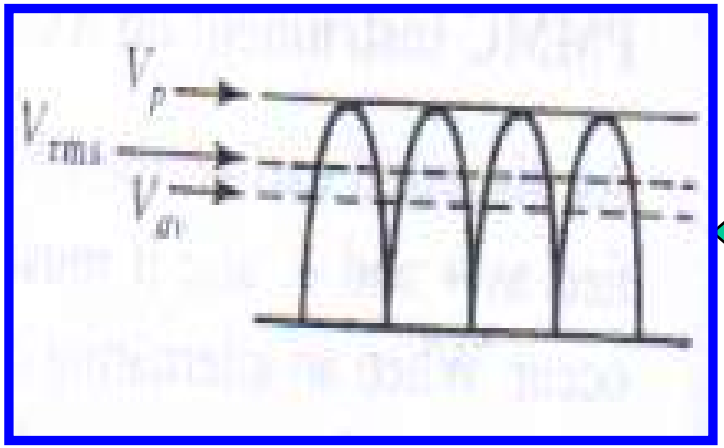
Average and RMS Value



Sine Wave

$V_{avg} = 0$

$V_{rms} = 0.707V_p$

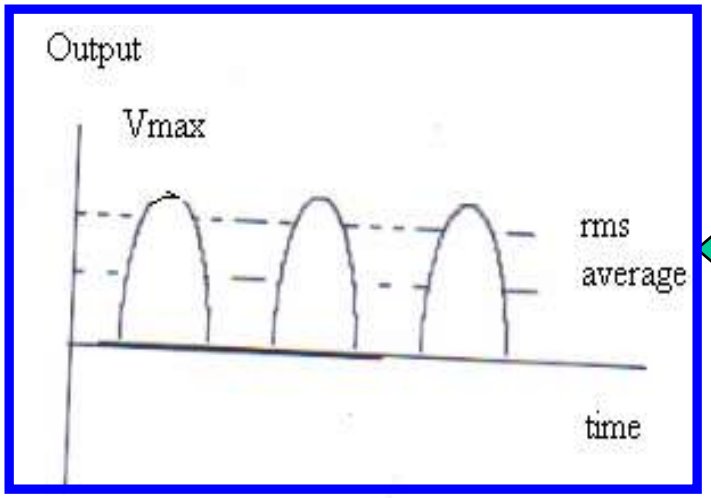


Full Wave

$V_{avg} = 0.636V_p$

$V_{rms} = 0.707V_p$

Cont..



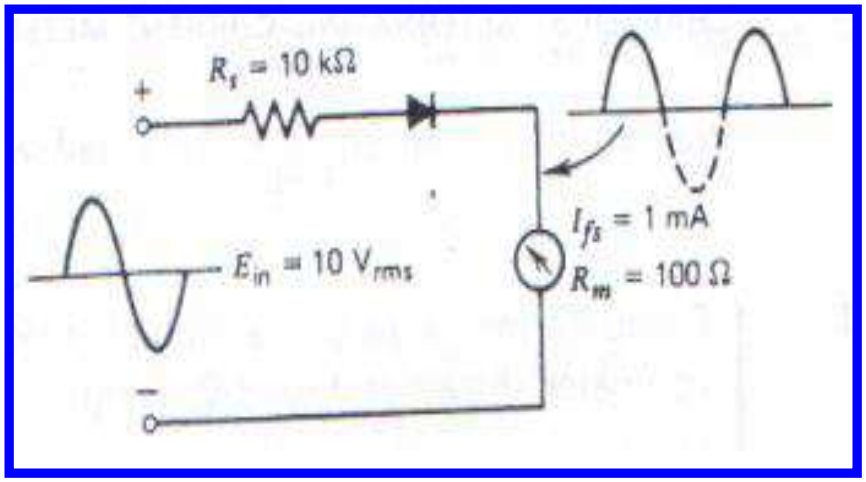
$V_{avg} = 0.318V_p$

$V_{rms} = 0.5V_p$

Half Wave

D'Arsonval meter movement used with half wave rectification

To convert alternating current (AC) to unidirectional current flow, which produces positive deflection when passed through a PMMC, the diode rectifier is used. Several types of rectifiers are selected such as a copper oxide rectifier, a vacuum diode, or semiconductor or "crystal diode".



$$V_{rms} = \frac{V_P}{2} = 0.5V_P$$

$$V_{ave} = V_{dc} = 0.318\,V_p$$

$$V_{ave} = \frac{V_p}{\pi} = \frac{\sqrt{2} \times V_{rms}}{\pi} = 0.45V_{rms}$$

Cont…

- For example, if the output voltage from a half wave rectifier is $10V_{rms}$ so the dc voltmeter will provide an indication of approximately 4.5V dc $\rightarrow$ Therefore, the pointer deflected full scale when 10V dc signal is applied.

- When we apply a 10Vrms sinusoidal AC waveform, the pointer will deflect to 4.5V $\rightarrow$ This means that the AC voltmeter is not as sensitive as DC voltmeter.

- In fact, **an AC voltmeter using half wave rectification is only approximately 45% as sensitive as a dc voltmeter.**

Cont…

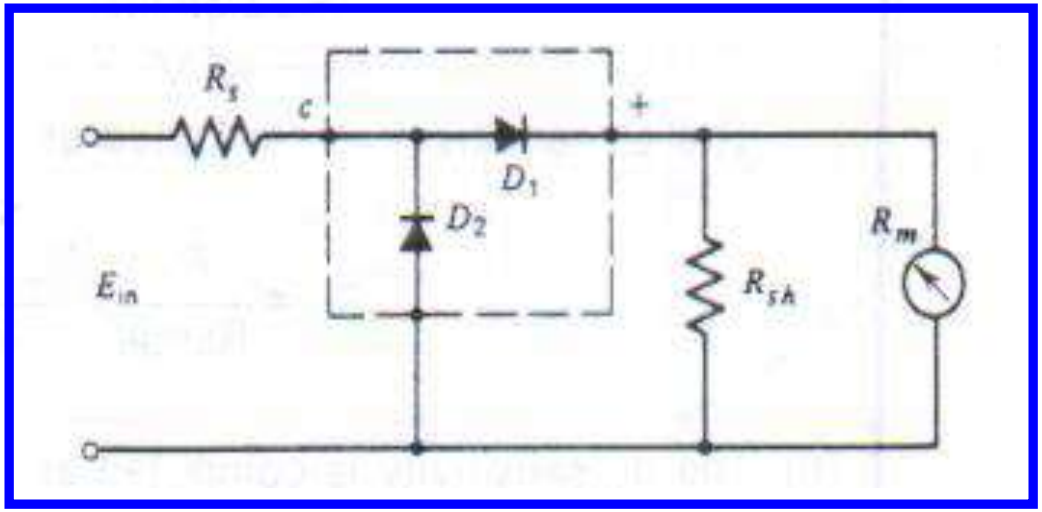
• Actually, the circuit would probably be designed for full-scale deflection with a 10V rms AC applied, which means the multiplier resistor would be only 45% of the value of the multiplier resistor for 10V dc voltmeter. Since we have seen that the equivalent dc voltage is equal to 45% of the rms value of the ac voltage.

$$R_s = \frac{E_{dc}}{I_{dc}} - R_m = \frac{0.45E_{rms}}{I_{dc}} - R_m$$

$$S_{ac} = 0.45S_{dc}$$

Cont..

Commercially produced ac voltmeters that use half wave rectification also has an additional diode and a shunt as shown in Figure below:



Cont..

- The additional diode D2 is reverse biased on the positive half cycle and has virtually no effect on the behavior of the circuit.
- In the negative half cycle, D2 is forward biased and provides an alternate path for reverse biased leakage current that would normally through the meter movement and diode D1.
- The purpose of the shunt resistor R_{sh} is to increase the current flow through D1 during positive half cycle so that the diode is operating in a more linear portion of its characteristic curve.
- Although this shunt resistor improves the linearity of the meter on its low voltage ac ranges, it also further reduces the AC sensitivity.

D'Ársonval Meter Movement: PMMC used in a DC Ammeter

- Since the windings of the moving coil are very fine wire, the basic d'Arsonval meter movement has only limited usefulness without modification.
- One desirable modification is to increase the range of current that can be measured with the basic meter movement.
- This done by placing a low resistance called a shunt (R_{sh}), and its function is to provide an alternate path for the total metered current 'I' around the meter movement.

D'Ársonval Meter Movement: PMMC used in A DC Voltmeter

- The basic d'Ársonval meter movement can be converted to a dc voltmeter by connecting a multiplier R_s in series with the meter movement
- The purpose of the multiplier:
  - is to extend the voltage range of the meter
  - to limit current through the d'Arsonval meter movement to a maximum full-scale deflection current.

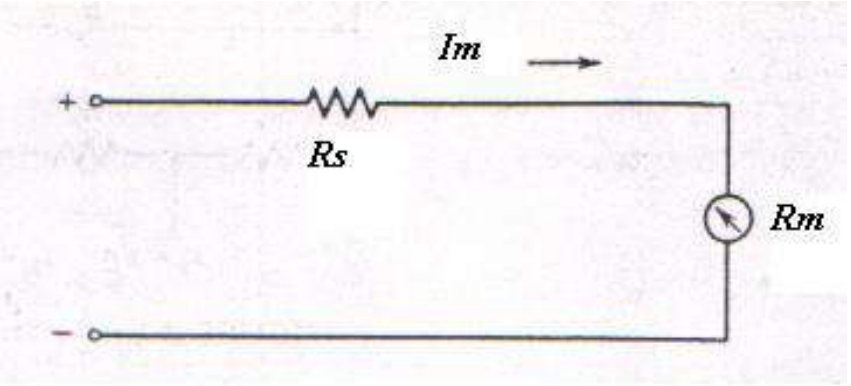


Fig 2-1 The basic d'Arsonval meter Movement Used In A DC Voltmeter

- To find the value of the multiplier resistor, first determine the sensitivity, S, of the meter movement.

$$\text{Sensitivity} = \frac{1}{I_{fs}} \ (\Omega/\text{V})$$

$$R_s = S \times \text{Range} - \text{Internal Resistance}$$

Summary

- Basic d'Arsonval meter movement – current sensitive device capable of directly measuring only very small currents.
- Large currents can be measured by adding shunts.
- Voltage can be measured by adding multipliers.
- Resistance – adding battery and a resistance network.
- All ammeters & voltmeters introduce some error – meter loads the circuit (common instrumentation problem).

Thank you