Transport Canada 1st Class Marine Engineering Exam Assistance Series

ELECTROTECH

PROBLEMS AND SOLUTIONS

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Presented by Martin's Marine Engineering Page
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These questions have been extracted from the examination papers in Volumes I and II of the Electrotechnology –Exams and Solutions.
It will assist you while studying Electrotechnology by "subject area", instead of having to laboriously find all the questions in Volumes I and II related to one subject area.

Equations

$V = I \cdot R$ $\qquad R = \frac{\rho \cdot l}{A}$

Resistors

Series $R_T = R_1 + R_2 + \dots$

Parallel $R_T = \left(\frac{1}{R_1} + \frac{1}{R_2} + \dots\right)^{-1}$

Capacitors

Series $C_T = \left(\frac{1}{C_1} + \frac{1}{C_2} + \dots\right)^{-1}$

Parallel $C_T = C_1 + C_2 + \dots$

$F = BIlz$ $\qquad P = T \cdot \omega$ $\qquad P = I \cdot V$

$E = B \cdot l v \cdot z$ $\qquad E = \frac{P \Phi N Z}{60 A}$ $\qquad A = P$ (lap) $\quad A = 2$ (wave) $\qquad T = K \Phi I_A$

$X_L = 2\pi f L$ $\qquad X_C = \frac{1}{2\pi f C}$ $\qquad Z = \sqrt{R^2 + (X_L - X_C)^2}$

$Q = CV$

Three Phase

$P = \sqrt{3}\, V_L I_L \cos\theta$

$f = \frac{PN}{120}$

Delta

$V_L = V_{ph}$

$I_L = \sqrt{3}\, I_p$

Star

$V_L = \sqrt{3}\, V_{ph}$

$I_L = I_{ph}$

$\eta = \frac{P_{OUT}}{P_{IN}}$

Magnetism

$H = \frac{F_m}{2\pi r}$ $\qquad \mu_0 = \frac{B}{H}$

$R_m = \frac{l}{\mu A}$

Transformers

$\alpha = \frac{N_1}{N_2} = \frac{V_1}{V_2}$

$E = 4.44 N f \Phi$

Synchronizing

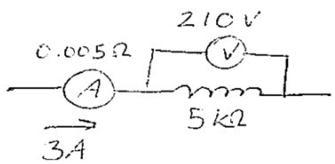
$E_r = 2E \sin\theta/2$ $\qquad P_{sync} = E_Z \cdot I_{sync} \cos\theta/2$

$I_{sync} = \frac{E_r}{2 \cdot X_{ph}}$

1. To find the resistance of a coil, an ammeter and a voltmeter are used. The ammeter which has a resistance of 0.005 ohm, is connected in series with the coil, and the voltmeter which has a resistance of 5000 ohms is connected across the ends of the coil.

   When the voltmeter registers 210 volts the ammeter registers 3 amperes. The resistance of the coil was them calculate from the voltmeter reading divided by the ammeter reading. Calculate the % error in this value.

3.



$$R_{measured} = \frac{V}{I} = \frac{210V}{3A} = 70\,\Omega$$

$$I_V = \frac{210V}{5000\Omega} = 42.0mA$$

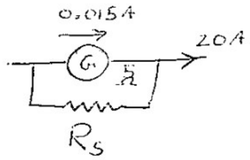
$$I_{COIL} = 3A - 42.0mA = 2.958A$$

$$R_{ACTUAL} = \frac{V}{I} = \frac{210V}{2.958A} = 70.9939\,\Omega$$

$$\%\ error = \frac{70.9939 - 70}{70.9939} = 1.4\%$$

2. Given a meter movement that has full scale deflection current of 0.015A and 5ohms resistance. Calculate the shunt resistor required to sue this meter in a 20 amperes circuit and also the multiplier resistor that would be necessary to use it in a 50V circuit.

1.



$I_R = 20 - 0.015A$

$= 19.985A$

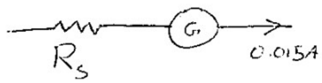
$V_R = I_G \cdot R_G$

$= (0.015)(5)$

$= 0.075V$

$$R_s = \frac{V_s}{I_s} = \frac{0.075V}{19.985A}$$

$$= \underline{\underline{3.75\,m\Omega}}$$



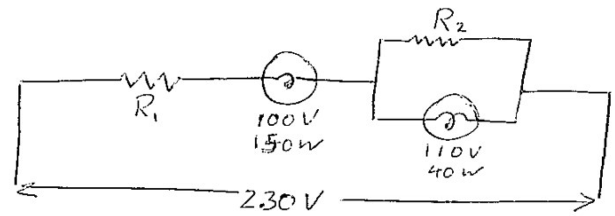
$V_R = 50 - 0.075$

$= \underline{49.925V}$

$$R_s = \frac{V_s}{I_s} = \frac{49.925}{0.015} = \underline{\underline{3328\,\Omega}}$$

3. Two lamps with the following characteristics are to be connected in series across a 230V supply. Indicate by sketch and calculation how they can be connected so that they operate within their characteristics. One lamp is 110V at 40W whilst the other is 100V at 150V. Resisters may be used to complete the circuit.

5.



$$I_{40} = \frac{40}{110} = \underline{0.364\,A} \qquad I_{150} = \frac{150}{100} = \underline{1.5\,A}$$

$$R_{40} = \frac{110}{0.364} = \underline{302.2\,\Omega} \qquad R_{150} = \frac{100}{1.5} = \underline{66.7\,\Omega}$$

Current through R_2

$$I_{R_2} = 1.5A - 0.364A$$
$$= 1.136A$$

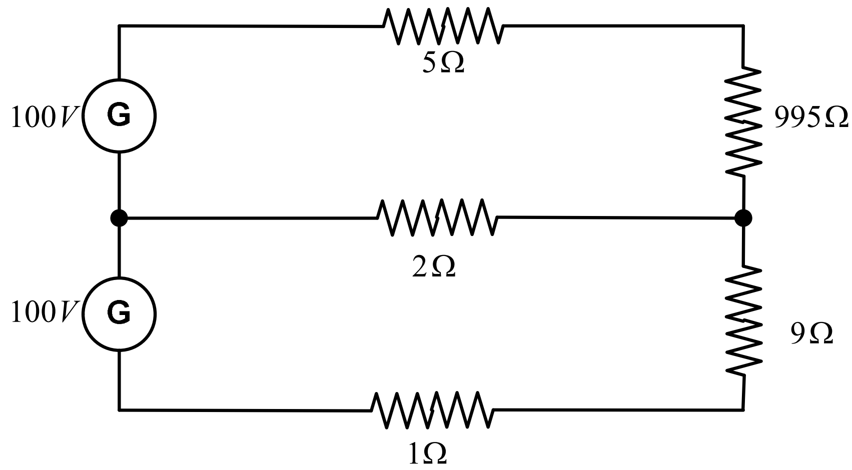
$$R_2 = \frac{110V}{1.136A} = \underline{\underline{96.8\,\Omega}}$$

Voltage drop across R_1

$$V_{R1} = 230 - 100 - 110$$
$$= \underline{20V}$$

$$R_1 = \frac{20V}{1.5A} = \underline{\underline{13.3\,\Omega}}$$

4. Calculate the current through the 2ohm resistor.



1. $100 - 5i_1 - 995i_1 - 2(i_1 - i_2) = 0$

$100 - 1002i_1 + 2i_2 = 0$

① $50 - 501i_1 + i_2 = 0$

$100 - 2(i_2 - i_1) - 9i_2 - 1i_2 = 0$

$100 - 12i_2 + 2i_1 = 0$

② $50 - 6i_2 + i_1 = 0 \Rightarrow \underline{i_1 = 6i_2 - 50}$

$50 - 501(6i_2 - 50) + i_2 = 0$

$50 + 25050 - 3006i_2 + i_2 = 0$

$25100 = 3005i_2$

$i_2 = \underline{\underline{8.353\,A}}$

$i_1 = \underline{\underline{0.118\,A}}$

5. A battery of six cells in series, each cell has an e.m.f of 1.5 volts and internal resistance of 0.5 ohm, is connected to resistances of 6, 12 ohms separately at first and then with the two resistance in parallel across the battery terminals. Calculate the current through each resistance in each of the cases.

4.

$$V = 6(1.5) = \underline{\underline{9\ V}}$$

$$r = 6\ (0.5) = \underline{\underline{3\ \Omega}}$$

$$R_1 = 6\Omega$$

$$R_2 = 12\ \Omega$$

$$R_{parallel} = \left(\frac{1}{6} + \frac{1}{12}\right)^{-1} = 4\Omega$$

$$I_1 = \frac{9V}{9\Omega} = \underline{\underline{1.0\ A}}$$

$$I_2 = \frac{9V}{15\Omega} = \underline{\underline{0.6\ A}}$$

$$I_{parallel} = \frac{9V}{7\Omega} = \underline{1.286\ A}$$

$$V_{parallel} = 9 - 1.286\ (3) = \underline{5.142\ V}$$

$$I_6 = \frac{5.142\ V}{6\ \Omega} = \underline{\underline{0.857\ A}}$$

$$I_{12} = \frac{5.142\ V}{12\ \Omega} = \underline{\underline{0.4285 A}}$$

6. Six electric cells are connected together in series. The e.m.f of each cell is *1.2V* and its internal resistance is *0.4 ohm*. Three wires A, B, can C whose resistances are *5, 40*, and *200 Ohms* respectively, and can be connected between the battery terminals. Determine the current which flows when each wire is inserted separately and also determine the current which flow when they are inserted together as a parallel group.

3.

$$V = 6(1.2V) = \underline{\underline{7.2V}}$$

$$R_A = 5\Omega$$
$$R_B = 40\Omega$$
$$R_C = 200\Omega$$

$$r = 6(0.4\Omega) = \underline{\underline{2.4\Omega}}$$

$$R_{parallel} = \left(\frac{1}{5} + \frac{1}{40} + \frac{1}{200}\right) = \underline{4.348\Omega}$$

$$I_A = \frac{7.2V}{5 + 2.4} = \underline{\underline{0.973A}}$$

$$I_B = \frac{7.2V}{42.4\Omega} = \underline{\underline{0.1698A}}$$

$$I_C = \frac{7.2V}{202.4\Omega} = \underline{\underline{0.036A}}$$

$$I_{Parallel} = \frac{7.2V}{(4.348 + 2.4)} = \underline{\underline{1.067A}}$$

7. A wire is 60metres long and weighs 200 grams. A second wire is 70ft long and weights 6 ozs. The specific resistance of the second wire is 10% less than that of the first and the material of the first wire is 2% less in weight per cubic inch than the material of the second wire. Find the ratio of resistance of second wire to that of the first.

1. $\ell_1 = 60\,m$ $\quad$ $\ell_2 = 70\,ft = 21.336\,m$

$m_1 = 200\,g$ $\quad$ $m_2 = 6\,oz = 170.25\,g$

Assume Cu

$\rho = 8.77\,g/cm^3$ $\quad$ $\rho_2 = 0.9\rho_1$ resistivity

$\rho_1 = 0.98\rho_2$

$\rho_1 = 8.77\,g/cm^3$ $\quad$ $\lambda_1 = \frac{200\,g}{60\,m} = 3.33\,g/m$

$\rho_2 = \frac{8.77}{0.98} = 8.95\,g/cm^3$ $\quad$ $R = \frac{\rho \ell}{A}$

$$V_{Cu} = \frac{21.336\,m\,(3.33\,g/m)}{8.77\,g/cm^3} = 8.101\,cm^3$$

$$V_{alloy} = \frac{170.25\,g}{8.95\,g/cm^3} = 19.02\,cm^3$$

$$A_{Cu} = \frac{8.101\,cm^3}{21.336\,m} = 0.38\,cm^2 \qquad R_{Cu} = \frac{\rho_1\,(21.336\,m)}{0.38\,cm^2}$$

$$A_{alloy} = \frac{19.02\,cm^3}{21.336\,m} = 0.8915\,cm^2 \qquad R_{alloy} = \frac{0.9\rho_1\,(21.336\,m)}{0.8915\,cm^2}$$

$$\frac{R_{Cu}}{R_{alloy}} = \frac{\dfrac{\rho_1\,\cancel{(21.336)}}{0.38\,cm^2}}{\dfrac{0.9\rho_1\,\cancel{(21.336)}}{0.8915}} = \frac{0.8915}{0.9(0.38)} = 2.607:1$$

8. An electric heater consists of 8 elements connected in parallel to a 220 volt supply and heats up 10 tonnes of oil 35°C in a 24 hour period. If the specific heat of the oil is 2.17Kj/kg/ °C and the efficiency of the heater is 70%.
   - Find the current taken.
   - Find the resistances of one of the elements if they are all of the same value.

2. 8 elements in parallel

$V = 220 V$

$m_{oil} = 10 t$

$\Delta T = 35 °C / 24 \text{ hours}$

$C_{oil} = 2.17 \text{ kJ/kg °C}$

$\eta = 70\%$

$$Q = mc\Delta T$$
$$= 10000 (2.17)(35)$$
$$= 759500 \text{ kJ/day}$$
$$= 8.79 \text{ kW}$$

$$P_{in} = \frac{8.79 \text{ kW}}{0.7} = 12.56 \text{ kW}$$

$$I_T = \frac{12.56 \text{ kW}}{220 \text{ V}} = 57.09 A$$

$$R_{parallel} = \left(\frac{8}{R_{element}}\right)^{-1}$$

$$R_T = \frac{220 V}{57.09 A} = 3.854 \Omega$$

$$3.854 = \frac{R_{element}}{8}$$

$$R_{element} = 30.832 \Omega$$

9. An electric heater in a 220V circuit raises the temperature of 3 tonnes of oil by 50°C every 12 hours. The efficiency of the heater is 80% and the specific heat of oil is $2KJ/kg, {}^{o}C$. Find the following:
    - Power consumption in kW hours,
    - The current taken and
    - The resistance of the heater element.

3. $V = 220\,V$

$m_{oil} = 3\,t$

$\Delta T = 50\,°C/12\,hour$

$C_{oil} = 2\,KJ/kg\,K$

$\eta = 80\,\%$

$$Q = mc\Delta T$$
$$= (3000)(2)(50)$$
$$= 300\,000\,KJ/12\,hours$$
$$= 6.94\,kW$$

$$P_{in} = \frac{6.94\,kW}{0.8} = 8.675\,kW$$

$$\text{Power consumption} = 8.675\,kW\,(12\,hours)$$
$$= \underline{\underline{104.1\,kWh}}$$

$$I = \frac{8.675 \cdot 10^3\,W}{220\,V} = \underline{\underline{39.43\,A}}$$

$$R = \frac{220\,V}{39.43\,A} = \underline{\underline{5.58\,\Omega}}$$

10. A lead wire and a copper wire are connected together in parallel. The currents flowing in the wires are in the ratio of *38:40* respectively and the lead wire is 60% longer than the copper wire. The ratio of the specific resistance of the wires is: Lead to copper – 208:16 Find the ratio of the cross-sectional area of lead wire to that of copper.

4.

Lead wire	Copper wire	
$I = 38\,A$	$I = 40\,A$	$R = \frac{\rho l}{A}$
$l_L = 1.6\, l_c$	l_c	
$\rho_L = 208\,\Omega/m$	$\rho_c = 16\,\Omega/m$	$I \propto \frac{1}{R}$

$$\frac{R_L}{R_{cu}} = \frac{\frac{\rho l}{A}}{\frac{\rho l}{A}}$$

$$\frac{\frac{1}{38}}{\frac{1}{40}} = \frac{\frac{(208)(1.6\, l_c)}{A_L}}{\frac{(16)(l_c)}{A_{cu}}}$$

$$1.0526 = \frac{332.8}{16} \cdot \frac{A_{cu}}{A_L}$$

$$\frac{A_{cu}}{A_L} = 0.0506$$

$$\frac{A_L}{A_{cu}} = \underline{\underline{19.76 : 1}}$$

11. Attempt the following:

i) Show how the electric potential difference (volt) is related to energy (or work) and quantity of charge.

2. A joule is a unit of work. A coulomb is a quantity of charge. A volt is the unit of electrical potential difference.

To relate all three: One joule of work is done when one coulomb is passed through a potential difference of one volt.

Mathematically: $\mathcal{E} = \text{volts}/\text{metre} = \text{Force}/\text{coulomb}$

$\mathcal{E}$ = electric field intensity

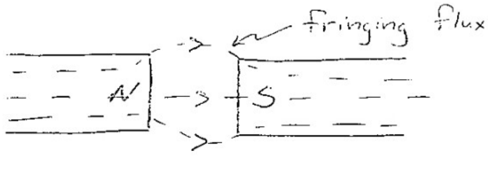
$\therefore$ volts × Coulombs = Force × metre

$W = QV = F \cdot d$

12. State the definition of the ampere in terms of it's coherence as a basic or fundamental unit in the International System of Units (SI).
Using a sketch indicate what is meant by "fringing" and by "leakage" in a magnetic circuit.
What is the magnetic flux density at a distance of 5cm from a very long straight wire carrying a current of 150A? Include units in your numerical solution and show that your answer has the correct units.

Note: $\mu_0 = 4\pi 10^{-7}$

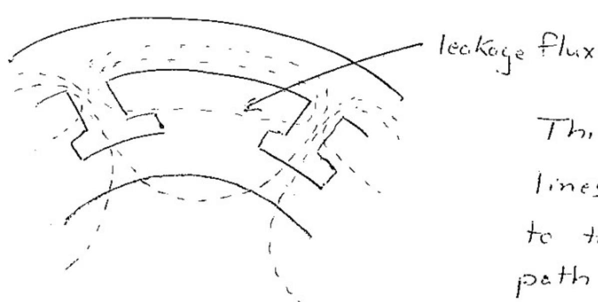
One ampere is defined as that current required such that the force between two infinitely long wires spaced one meter apart is $2 \cdot 10^{-7}$ N.



Magnetic Fringing

This diagram shows the manner in which flux is known to bridge an air gap, especially if the gap is large.

Flux in air tends to occupy a larger area than that of the iron and the flux density is reduced. A correction factor in designing magnetic circuits can be included in computations for this.



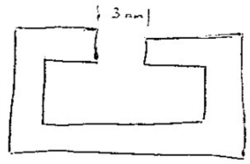
Magnetic Leakage

This is where some of the lines of flux are not confined to the iron and complete their path through air. A leakage flux factor may be used to compensate for this.

Flux linkage = $N\phi$

13. A magnetic circuit is built up of rectangular metal plates 60mm wide, having a combined depth of 80mm and with the insulating material between the laminations accounting for 10% of the depth. The circuit has a mean length of 1.8 with the air gap of length 3mm and a cross sectional area of 500mm^2. Assume a leakage factor of 1.1; the relative permeability of iron as 2500 and permeability of space as $4\pi \times 10^{-7}$. Calculate the magnetomotive force required to produce a flux of 0.006Wb across the air gap.

3.



$\phi = 0.006$ wb

leakage = 1.1 $\qquad \phi = \underline{\underline{0.0066 \text{ wb}}}$

$\mu_{IRON} = 2500$

$\mu_0 = 4\pi \cdot 10^{-7}$

$A = 500 \text{ mm}^2$

$l = 1800$ mm

$l_{IRON} = 1797$mm

$$R_m(Air) = \frac{l}{\mu A} = \frac{3 \cdot 10^{-3} m}{(4\pi \cdot 10^{-7})(500 \cdot 10^{-6} m^2)} = 4.777 \cdot 10^6 \text{ At/wb}$$

$$R_m(Iron) = \frac{l}{\mu A} = \frac{1797 \cdot 10^{-3}}{2500(500 \cdot 10^{-6})(4\pi \cdot 10^{-7})} = 1.145 \cdot 10^6 \text{ At/wb}$$

$$R_{m_T} = (4.777 + 1.145) \cdot 10^6 = 5.922 \cdot 10^6 \text{ At/wb}$$

$$F_m = (5.922 \cdot 10^6)(0.0066) = \underline{\underline{39085 \text{ At}}}$$

14. A coil of 200 turns is rotated at 1200 rpm between poles of an electromagnet. Flux density is 0.02 tesla. Axis of rotation is at right angles to the field. Effective of the coil is 0.3 metre, mean width 0.2 metre. Assuming e.m.f. produced is sinusoidal, find the following:

i) Maximum value of e.m.f.

ii) Frequency

1. 200 turns

$N = 1200$ rpm

$B = 0.02$ T

$l = 0.3$ m

$\phi = 0.2$ m

$$V = \frac{1200}{60}(0.1)(2\pi) = 12.57 \text{ m/s}$$

$$f = \frac{1200}{60} = 20 \text{ Hz}$$

$$E = Blv \cdot Z$$

$$= (0.02)(0.3)(12.57)(400)$$

$$= 30.168 \text{ V}$$

15. A moving coil permanent magnetic instrument has a resistance of 10 ohms and a flux density in the gap is 0.1 tesla. The coil has 100turns of wire and is of mean 300m and axial length is 25mmm. If a p.d. of 50 mV is required for full scale deflection, calculate the controlling torque exerted by the spring.

4.

$R = 10\,\Omega$

$B = 0.1\,T$

$Z = 100 \times 2 = 200$

$\varnothing = 0.300\,m$

$\ell = 0.025\,m$

$V = 50\,mV$

$I = \frac{50\,mV}{10\,\Omega} = 5\,mA$

$F = BI\ell Z = (0.1)(5 \cdot 10^{-3})(0.025)(200) = \underline{\underline{2.50\,mN}}$

$T = F \cdot r = (2.50 \cdot 10^{-3})(0.150) = \underline{\underline{3.75 \cdot 10^{-4}\,Nm}}$

16. The following results of measurements are taken at intervals over a half cycle of AC voltage.

Time (milliseconds)	0	0.45	0.95	1.5	2.1	2.5	3.1	3.9	4.5	5.0
Volts	0	20	36	40	37.5	33	32	31	20	0

Calculate the R.M.S. value of voltage and the frequency of the waveform.

With plot of numbers to scale and base time equally divided, find voltage values for each interval.

→ square each value and take average of all

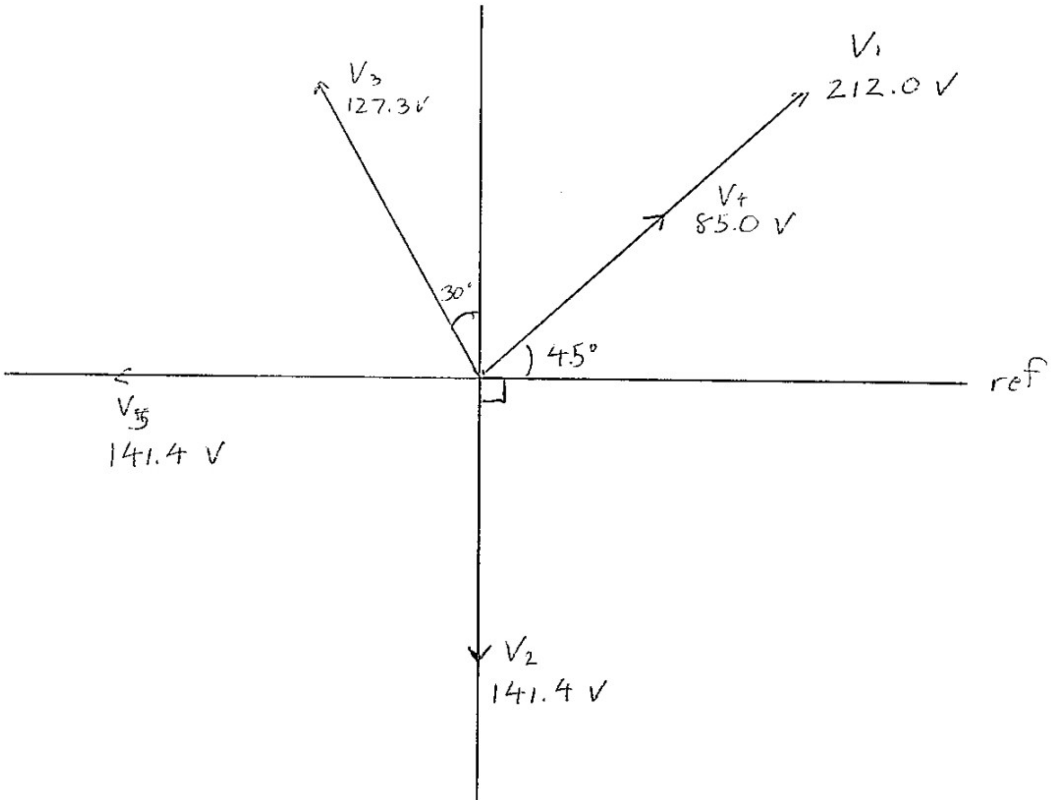
→ take square root of average $\sqrt{\overline{V}^2} = V_{RMS}$

→ Time for one cycle = 10 ms

$f = \frac{1}{T} = \underline{\underline{100\ Hz}}$

17. Express each of the following voltages in phasor notation and locate them on a phasor diagram:

$$V1 = 212.0\ \sin(wt + 45\ \deg)$$
$$V2 = 141.4\ \sin(wt - 90\ \deg)$$
$$V3 = 127.3\ \cos(wt + 30\deg)$$
$$V4 = 85.0\ \cos(wt - 45\deg)$$
$$V5 = 141.4\ \sin(wt + 180\ \deg)$$



$V_1 = 212.0\ V\ \angle 45°$ lead

$V_2 = 141.4\ V\ \angle 90°$ lag

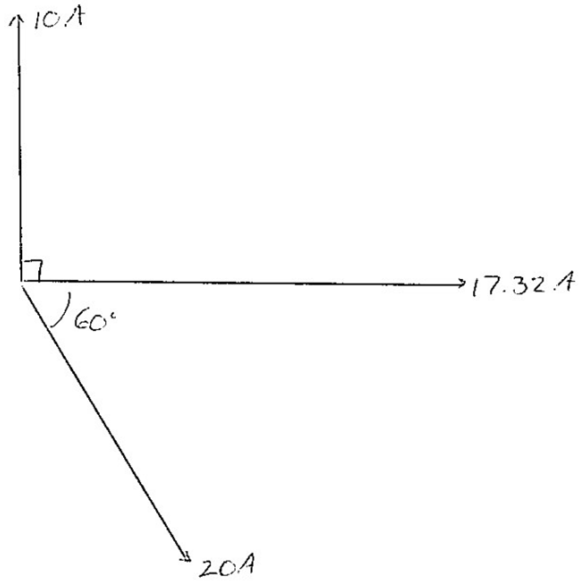
$V_3 = 127.3\ V\ \angle 120°$ lead

$V_4 = 85.0\ V\ \angle 45°$ lead

$V_5 = 141.0\ V\ \angle 180°$ lead

18. Three currents of peak values 10A, 17.32A and 20A respectively meet in a common conductor. The 17.32A current lags the 10A current by 90 electrical degrees, and leads the 20A current by 60 electrical degrees.

Find the value of the resultant current giving its phase relation to the 10A current



I	I_x	I_y
I_1	0	10
I_2	17.32	0
I_3	10	-17.32
	27.32	-7.32

$$I_R = \sqrt{27.32^2 + 7.32^2}$$

$$= 28.28A$$

$$\theta = \tan^{-1}\left(\frac{-7.32}{27.32}\right)$$

$$= -15.0°$$

$$I_R = 28.28A \angle 15° \text{ lag}$$

19. Discuss the relationship between RMS, Average and Form Factor.

A transformer has a primary voltage of 240V and a secondary voltage of 17200V; the primary resistance is 0.00033 ohm and the secondary resistance is 13 ohms. Out is 10KVA.

5. RMS → the AC voltage that will provide the same heating effect in a resistance element as the same steady state DC.

→ 0.707 of the max value of one half cycle of a sine wave voltage

→ represents Root, Mean, Square value

Average → 0.636 of max for sine wave

→ other waveforms: take value samples at equal intervals and average them through one half cycle.

Form Factor → states how near a wave form approaches the theoretical sine wave

→ ratio of RMS to average

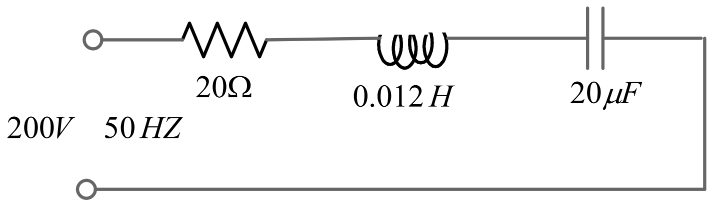
$$= \frac{\text{RMS value}}{\text{Average value}}$$

20. In the following circuit find the following:

i) impedance

ii) I_{line}

iii) Power Factor



11.

$V = 220\ V$

$f = 50\ Hz$

$R = 20\Omega$

$L = 0.012H$

$C = 20\mu F$

$X_L = 2\pi(50)(0.012)$

$= 3.77\Omega$

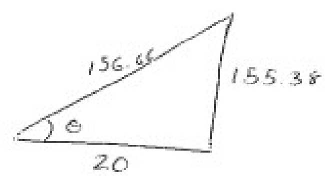
$X_C = \dfrac{1}{2\pi(50)(20\cdot 10^{-6})}$

$= 159.15\Omega$

$Z = \sqrt{20^2 + (3.77 - 159.15)^2}$

$= 156.66\Omega$

$I = \dfrac{V}{Z} = \dfrac{220V}{156.66\Omega} = 1.40A$



$p.f. = \cos\theta = \dfrac{20}{156.66} = 0.128$ lead

21. A circuit has a resistance of 3 ohms and an inductance of 0.01 Henry. The voltage across this circuit is 60V and the frequency is 50HZ. It is a series circuit. Calculate the following:

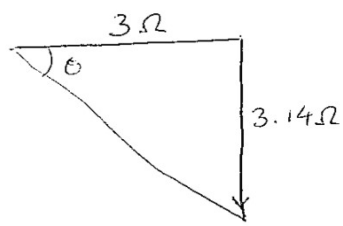
i) Impedance
ii) Line Circuit
iii) Power Factor
iv) Power Absorbed

4.

$R = 3\,\Omega$
$L = 0.01\,H$
$V = 60\,V$
$f = 50\,Hz$

$X = 2\pi f L = 2\pi(50)(0.01) = 3.14\,\Omega$

$Z = \sqrt{3.14^2 + 3^2} = 4.34\,\Omega$



$\tan\theta = \frac{3.14}{3}$

$\theta = 46.31^\circ$

$pf = \cos\theta = 0.691$ lag

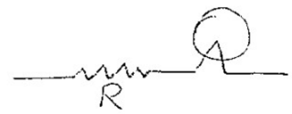
$I = \frac{V}{R} = \frac{60}{4.34} = 13.82\,A$

$P_{absorbed} = \frac{V^2}{Z}\cos\theta = \frac{60^2}{4.34}(0.691) = 573.2\,W$

22. A *100W* lamp for a *100V* supply is placed across a 220V supply. What values of resistance must be placed in series with it so that it will work under its proper conditions? If a coil is used instead of the resistor and if the resistance of the coil is small compared to the reactance, what is the inductance of the coil? The frequency is 50HZ. What is the total power absorbed in each case?

100 w lamp for 100 V

$V = 220\ V$



$P = VI$

$100 = 100(I)$

$I = 1\ A$

$V_R = 120\ V$

$R_{Lamp} = \frac{100}{1^2} = 100\ \Omega$

$R = \frac{V}{I} = \frac{120}{1} = \underline{\underline{120\ \Omega}}$

<u>Using a coil</u>

$V = IZ$

$220 = (1)\ Z$

$Z = 220\ \Omega$

$X_L = \sqrt{Z^2 - R^2}$

$= \sqrt{220^2 - 100^2}$

$= 196\ \Omega$

$X = 2\pi f L$

$L = \frac{196}{2\pi(50)}$

$= \underline{\underline{0.624\ H}}$

$P_1 = I^2 R$

$= (1)(220)$

$= \underline{\underline{220\ W}}$

$P_2 = I^2 R$

$= (1)(100)$

$= \underline{\underline{100\ W}}$

23. A coil has a resistance of 15 ohms and in inductance of 0.05 H. calculate the impedance and power absorbed by the coil in watts when it is connected to a $100V \quad 50\,HZ$ A.C. supply.

$R = 15\,\Omega$

$L = 0.05H$

$V = 100V$

$f = 50\,Hz$

$X = 2\pi f L$

$= 2\pi(50)(0.05)$

$= 15.71\,\Omega$

$Z = \sqrt{15^2 + 15.71^2}$

$= 21.72\,\Omega$

$I = \frac{V}{Z} = \frac{100\,V}{21.72\,\Omega} = 4.60\,A$

$P = I^2 R$

$= (4.6)^2(15)$

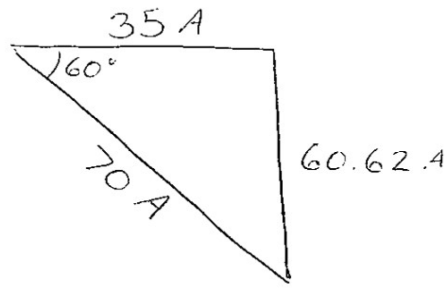
$= 317.4\,W$

24. Given a 100V supply with a 70A current at 60degrees lagging. Calculate the following:

   i) resistance
   ii) impedance
   iii) X_L inductive reactance

$V = 100\ V$

$I = 70\ A\ @\ 60°\ lag$



$V \cdot I_{35} = I_{70}^2 \cdot R$

$R = \frac{100(35)}{70^2}$

$= 0.714\ \Omega$

$Z = \frac{V}{I} = \frac{100}{70} = 1.429\ \Omega$

$X = \sqrt{1.429^2 - 0.714^2}$

$= 1.238\ \Omega$

25. Given 220 volts, 60 HZ and a series circuit with 50 ohms resistance, 0.01 Henry inductance and $8\mu F$ capacitance. Find the line current and power absorbed.

10.

$V = 220\ V$

$f = 60\ Hz$

$R = 50\ \Omega$

$L = 0.01\ H$

$C = 8\ \mu F$

$$X_L = 2\pi f L = 2\pi(60)(0.01) = 3.77\ \Omega$$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(60)(8\cdot 10^{-6})} = 331.57\ \Omega$$

$$Z = \sqrt{50^2 + (3.77 - 331.57)^2} = 331.59\ \Omega$$

$$I = \frac{V}{Z} = \frac{220\ V}{331.59\ \Omega} = \underline{\underline{0.663\ A}}$$

$$P = I^2 R = (0.663)^2(50) = \underline{\underline{21.98\ W}}$$

26. A circuit has a resistance of 3ohms and an inductance of 0.01 H. The voltage across this circuit is 60V and the frequency is 50 HZ. Calculate the following:

i) Impedance

ii) Line Current

iii) P.F.

iv) Power Absorbed

4. $R = 3\,\Omega$

$L = 0.01\,H$

$V = 60\,V$

$f = 50\,Hz$

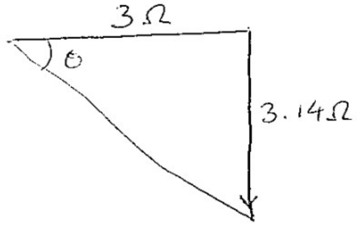
$X = 2\pi f L$

$= 2\pi(50)(0.01)$

$= 3.14\,\Omega$

$Z = \sqrt{3.14^2 + 3^2}$

$= 4.34\,\Omega$



$\tan\theta = \dfrac{3.14}{3}$

$\theta = 46.31°$

$pf = \cos\theta$

$= 0.691$

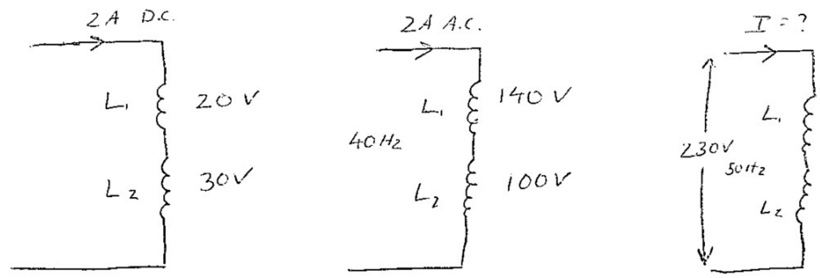
$I = \dfrac{V}{R} = \dfrac{60}{4.34} = 13.82\,A$

$P_{absorbed} = \dfrac{V^2}{Z}\cos\theta = \dfrac{60^2}{4.34}(0.691)$

$= 573.2\,W$

27. Two coils are connected in series, when 2 amperes direct current are passed through, voltage drops are 20 and 30 volts respectively. When 2 amperes alternating current at 40 hertz is passed through, the voltage drops are 140 and 100 volts respectively. Find the current when the circuit is connected to 230v 50Hz.

1.



$$R_1 = \frac{V}{I} = \frac{20}{2} = 10\,\Omega \qquad Z_1 = \frac{140}{2} = 70\,\Omega$$

$$R_2 = \frac{V}{I} = \frac{30}{2} = 15\,\Omega \qquad Z_2 = \frac{100}{2} = 50\,\Omega$$

$$X_1 = \sqrt{70^2 - 10^2} = 69.28\,\Omega \qquad X_1 = 2\pi f L_1$$

$$X_2 = \sqrt{50^2 - 15^2} = 47.70\,\Omega \qquad L_1 = \frac{69.28}{2\pi(40)} = 0.2757\text{ H}$$

$$L_2 = \frac{47.70}{2\pi(40)} = 0.1898\text{ H}$$

At 50Hz

$$X_1 = 2\pi(50)(0.2757) = 86.61\,\Omega \qquad Z_1 = \sqrt{86.61^2 + 10^2} = 87.19\,\Omega \qquad Z_T = 148.68\,\Omega$$

$$X_2 = 2\pi(50)(0.1898) = 59.63\,\Omega \qquad Z_2 = \sqrt{59.63^2 + 15^2} = 61.49\,\Omega$$

$$I = \frac{230\text{ V}}{148.68\,\Omega} = \underline{\underline{1.55\text{ A}}}$$

28. A coil when connected with a 120V direct current supply consumes 600 watts. When the same coil is connected with a 260V alternating current supply the consumption is 2400 watts. Find the inductive reactance of the coil.

9.

$P_{DC} = 600\ W \qquad V = 120\ V\ D.C.$

$P_{AC} = 2400\ W \qquad V = 260\ V\ A.C.$

$$P = \frac{V^2}{R}$$

$$R = \frac{120^2}{600} = 24\ \Omega$$

$$P = I^2 R$$

$$I = \sqrt{2400/24}$$

$$= 10\ A$$

$$Z = \frac{V}{I} = \frac{260\ V}{10\ A} = 26\ \Omega$$

$$X = \sqrt{26^2 - 24^2}$$

$$= \underline{\underline{10\ \Omega}}$$

29. A coil has a resistance of 400 ohms and an impedance of 498 ohms connected to a supply of 200v 60hz. The coil is then connected in series with a capacitor of $40\mu F$ and across a supply of $240V \ at \ 50\,HZ$.

i) Find the current that flows

ii) Find the voltage drop across the coil capacitor

5. $R = 400\,\Omega$

$Z_L = 498\,\Omega$ @ 60 Hz

$C = 40\,\mu F$

$V = 240\,V$

$f = 50\,Hz$

$X_L = \sqrt{498^2 - 400^2} = 296.65\,\Omega$

$L_1 = \frac{296.65}{2\pi(60)} = 0.787\,H$

$X_L(50) = 2\pi(50)(0.787\,H) = 247.2\,\Omega$

$X_C(50) = \frac{1}{2\pi(50)(40\cdot10^{-6})} = 79.58\,\Omega$

$Z = \sqrt{400^2 + (247.2 - 79.58)^2} = 433.7\,\Omega$

$I = \frac{V}{Z} = \frac{240\,V}{433.7\,\Omega} = \underline{\underline{0.553\,A}}$

$Z_L = \sqrt{400^2 + 247.2^2} = 470.2\,\Omega$

$V_C = I X_C = (0.553)(79.58) = \underline{\underline{44.0\,V}}$

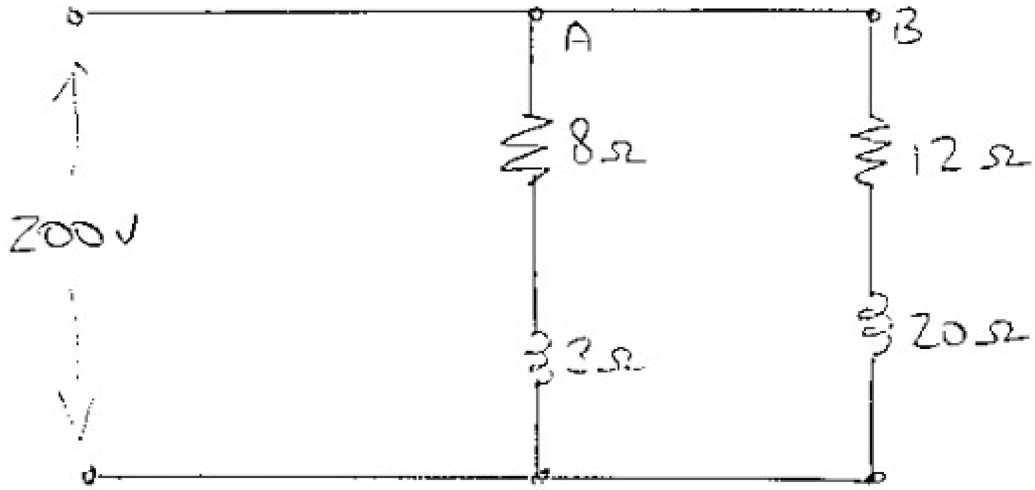
$V_L = I Z_L = (0.553)(470.2) = \underline{\underline{260\,V}}$

30. Given the following circuit find the following:

a. I_A

b. I_B and

c. I_{Line}



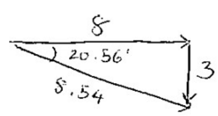
6.

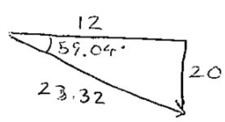
$$Z_A = \sqrt{8^2 + 3^2} = 8.54\,\Omega$$

$$Z_B = \sqrt{12^2 + 20^2} = 23.32\,\Omega$$

$$I_A = \frac{V}{Z_A} = \frac{200}{8.54} = 23.42\ A$$

$$I_B = \frac{V}{Z_B} = \frac{200}{23.32} = 8.58\ A$$





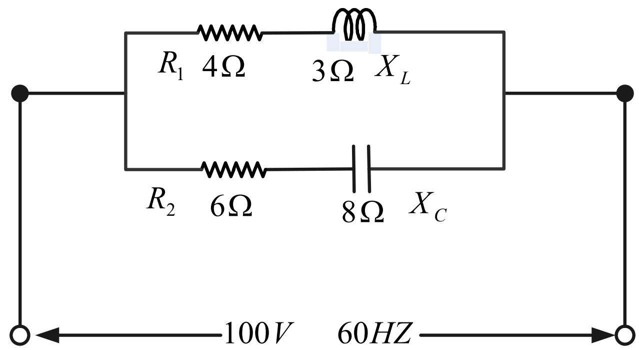
$$I_X = 23.42 \cos 20.56° + 8.58 \cos 59.04° = 26.34\ A$$

$$I_y = 23.42 \sin 20.56° + 8.58 \sin 59.04° = 15.58\ A$$

$$I = \sqrt{26.34^2 + 15.58^2} = 30.6\ A$$

31. For parallel circuit illustrated, calculate the following:

a. Equivalent impedance
b. Line circuit
c. Power factor
d. Power supplied to the circuit

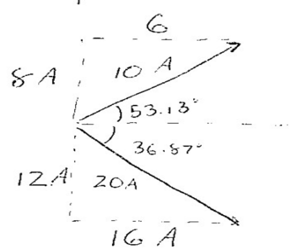


7.

$Z_A = \sqrt{4^2 + 3^2} = 5.0\,\Omega$ $Z_B = \sqrt{6^2 + 8^2} = 10.0\,\Omega$

$I_A = \frac{100\ V}{5.0\,\Omega} = 20\,A$ $I_B = \frac{100\ V}{10.0\,\Omega} = 10\,A$

$pf = \cos\theta = \frac{4}{5} = 0.8$ lag $pf = \cos\theta = \frac{6}{10} = 0.6$ lead



$I_{Line} = \sqrt{22^2 + 4^2} = 22.36\ A$

$pf = \cos\theta = \frac{22}{22.36} = 0.984$ lag

$Z = \frac{V}{I} = \frac{100}{22.36} = 4.47\,\Omega$

$P_1 = I^2R = 20^2(4) = 1600\ W$

$P_2 = I^2R = 10^2(6) = 600\ W$

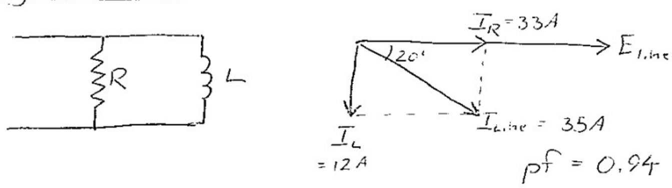
$P_{Total} = 2200\ W$

32. How can the Power Factor be improved in an A.C. system? How would methods to improve the P.F. affect the power consumed?

1. Power Factor Improvement

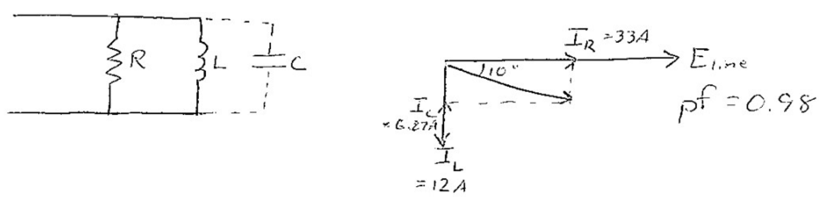
- improved in a system by providing a circuit element that will cause current to be drawn from the source that will reduce the original "out of phase" component of current, which will result in the I_{line} becoming more nearly in phase with E_{line}.

original circuit



- vectors show two components of branch current which produce out of phase component of line current.

improved circuit

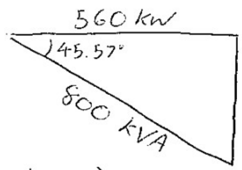


- to improve pf, an alternative capacitive path for current is made
- this current will be leading and is opposite in phase to the inductive current
- this will reduce the inductive current

∴ angle of lag will be reduced and power factor improved.

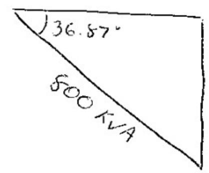
33. A 560kW Alternating Current generator has a power factor of 0.7. The Power Factor is raised to 0.8 with the same KVA, find the percentage increase in kW output.

3.



$\theta = \cos^{-1}(0.7)$

$= 45.57°$



$\theta = \cos^{-1}(0.8)$

$= 36.87°$

Kw loading $= 0.8(800)$

$= 640$ kw

Increase in KW loading available $= 640 - 560$

$= 80$ KW

% increase $= \frac{80}{560} = 14.29\%$

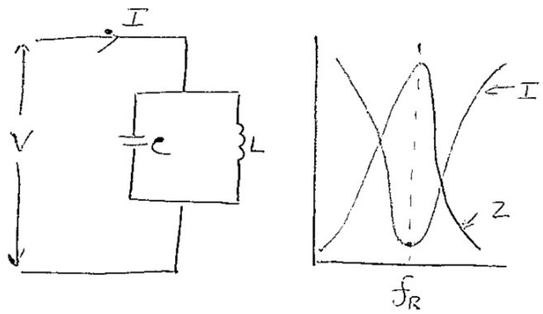
34. Answer the following with relation to Alternating Current and Voltage:

I. What is "resonant frequency"? Use graphs and describe the following in a parallel and series circuit.

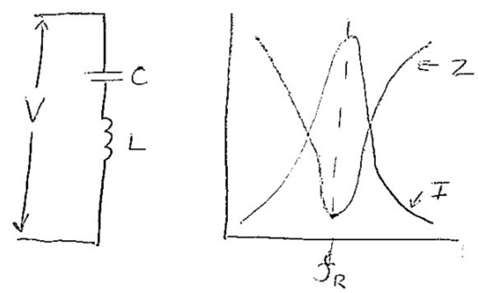
4. Resonant Frequency

- a condition in an A.C. circuit when the inductive reactance (X_L) = capacitive reactance (X_C).
- the curves of how current and impedance very with frequency for both series and parallel resonant circuits are shown:

Parallel Resonance



Series Resonance



- Each circuit acts opposite of each other
- Parallel: high impedance (Z) at resonant frequency
- Series: low impedance (Z) at resonant frequency
- acts oppositely w/ regards to current also

- equate X_L to X_C to obtain resonant frequency

$$X_L = X_C$$

$$2\pi f L = \frac{1}{2\pi f C}$$

$$f = \frac{1}{2\pi\sqrt{LC}}$$

35. For what purpose are transformers fitted in the electrical system of a ship?

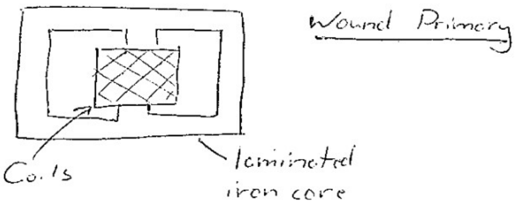
8. Fitting of Transformers

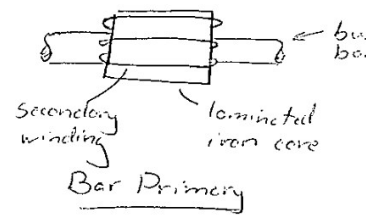
- fitted in a ship to facilitate distribution of power for different services throughout the ship at the required voltage

- they enable 3 phase power from the main bus to be broken down to the required voltages to feed three phase motors and also permit the distribution of single phase power at various voltages from the same 3ph. source.

36. Sketch and describe the construction of a current transformer.
What other salient features are incorporated to make the machine efficient?
Why must the secondary circuit of a current transformer never be opened when the primary is energized?

2.c)





Two types – Wound primary
– bar primary

Wound primary
- primary has few turns over secondary windings
- wrapped on laminated iron core

bar primary
- bus bar used as primary winding
- secondary windings wrapped around iron core placed over bus bar

→ both are strong to withstand high instantaneous currents and magnetic fields

→ primary winding either bus bar of few turns of low resistance wire

→ secondary is many turns of wire

→ instrument current typically 5 A

Must Have

→ ratio accuracy

→ small angular variation from 180° phase displacement between primary & secondary currents

→ sufficient rating to operate the connected burden

→ high insulation strength, mechanical rigidity, and ability to withstand heavy momentary currents.

2.b) - never open the secondary circuit while the primary is energized due to

① dangerously high voltage will occur in secondary

② will result in permanent installation of a residual magnetic field.

- to remove a meter from the secondary circuit, the circuit must be shorted by means of a shorting switch.

- switch remains closed until the meter is replaced

37. Given the following data on a transformer, calculate the following:

i) The primary voltage

ii) The turns ratio, also

iii) The primary current, and

iv) The secondary current.

Given data:

Secondary voltage $13200V$ — Primary turns 900

Primary flux 1×10^{-3} — KVA Output $440\,KVA$

Frequency $60\,HZ$

Derive the formula used in this problem.

2. c) $V_2 = 13200V$

$N_1 = 900$

$\Phi_1 = 0.001\,wb$

$KVA = 440\,KVA$

$f = 60\,Hz$

$$E_1 = 4.44\,N f \Phi = 4.44(900)(60)(0.001) = 240V$$

$$\alpha = \frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{240}{13200} = 1:55$$

$$I_1 = \frac{440\,KVA}{240V} = 1833.3A$$

$$I_2 = \frac{440\,KVA}{13200V} = 33.33A$$

b) $$E_{AVG} = \frac{N\phi}{t}$$

→ current & flux changes w/ time.

→ maximum change from zero to max in ¼ cycle

→ substitute $t = 1/4f$

$$E_{AVG} = \frac{N\phi}{1/4f} = 4N\phi f$$

→ for sine wave representation of RMS, need to multiply by 1.11

$$E_{AVG} = 4.44\,N\Phi f$$

38. Describe the construction of a transformer and what are it's functions?

A transformer has a primary winding o f800 turns and a secondary of 160 turns. It is rated at $10KVA\ AT\ 480volts$. Find the following:

I. Ratio of transformation
II. Approximate primary voltage
III. Rated full load secondary current
IV. Rated full load primary current, neglecting the "no load" current.

b) 10 KVA transformer

$V_2 = 480\text{ V}$

$N_1 = 800$

$N_2 = 160$

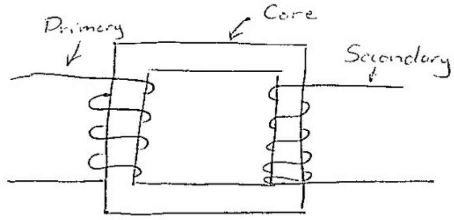
$$\alpha = \frac{N_1}{N_2} = \frac{800}{160} = 5:1$$

$$V_1 = V_2 \cdot \frac{N_1}{N_2} = 480(5) = 2400\text{ V}$$

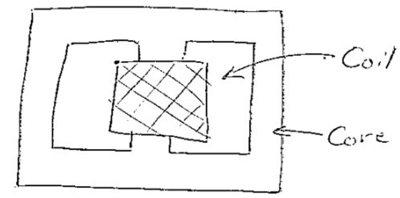
$$I_1 = \frac{10\text{ KVA}}{2400\text{ V}} = 4.17\text{ A}$$

$$I_2 = \frac{10\text{ KVA}}{480\text{ V}} = 20.83\text{ A}$$

1.



Core Type



Shell Type

- cores are made of special low loss steel and are laminated to minimize core losses
- core type : → windings surround laminated iron core
  - → primary winding on one side, secondary on other
  - → not used in commercial transformers due to large leakage flux
- shell type : → iron core surrounds windings

- transformers may be completely encased
- other in insulating oil → heat conduction

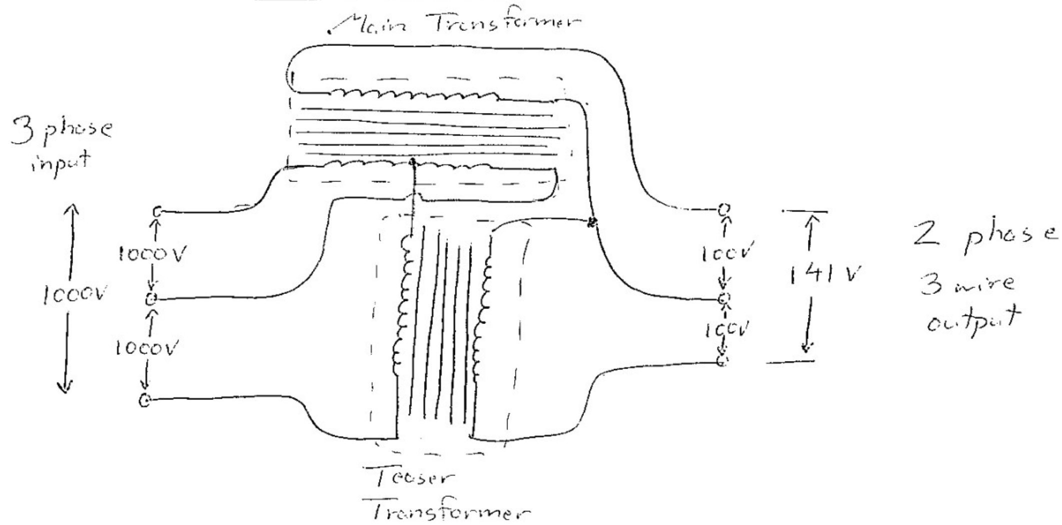
- coils → wound with copper or aluminum wire or strap
  - → insulated with cotton, cellulose, special papers, polyester glass tapes, etc.
  - → dried in O_2 free environment to remove moisture

- 2 winding types
  - ① concentric → cylindrical with one winding placed inside the other with insulation separating
  - ② pancake → built up with primary & secondary sections interleaved.

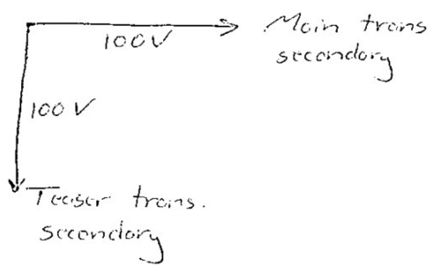
39. There is a method of connecting a transformer to obtain a two-phase three wire secondary output, from a three wire phase input.
Sketch a diagram to show this would be accomplished using the SCOTT TAP method. Show the position of the tap in the sketch.

5.

Scott Tap Method



- converts three phase voltages to a three wire, two phase system

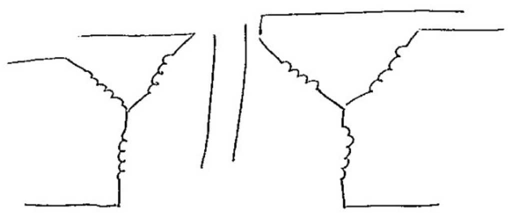


40. Three phase transformers may be connected in banks in the following manner:

I. delta delta
II. delta way
III. wye wye
IV. wye delta

Discuss the particular application each would be used for and state the advantages or disadvantages ensuring from such application.

1. a) Wye - Wye

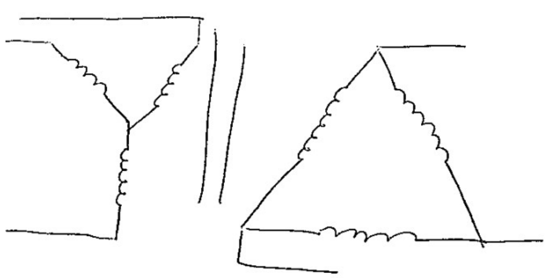


- only 57.7% of V_L is impressed upon each winding but full I_L flows in each

Advantages
- flexibility → can obtain two voltages (V_L or V_{pn})

Disadvantages
- no neutral → must have balanced loads
- power circuits from wye-wye bank cause disturbance in communication circuits in their immediate vicinity

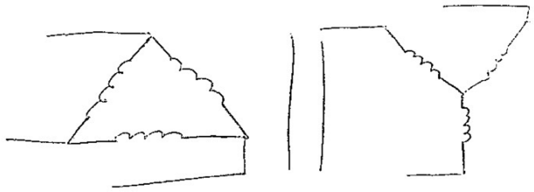
b) Wye - Delta



- step down high transmisson line voltages to lower voltages

Advantage
- can step down voltage by transformation ratio and $\sqrt{3}$.
- reduction in insulation requirements

c) Delta - Wye

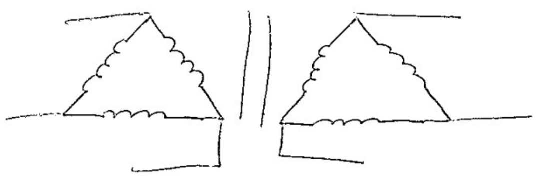


- used to transform up
- used in generating plants to step voltage up for transmission.

Advantages

- can step up voltage by transformation ratio and $\sqrt{3}$.
- reduction in insulation requirements
- permits more flexibility in distribution (208/120 possible w/ neutral on wye)

d) Delta - Delta



Advantages

- can operate in "open-delta" if one winding becomes damaged

Disadvantage

- "open-delta" reduces capacity to 57.7% of full.

41. Give the advantages of using ultra high voltages in the transmission of electric power between the sources of generation and the load point. A transformer with a rating of $2400-240\ volts$ has 2000 turns on the primary winding. Assuming a 3 voltage drop in the transformer when fully loaded, how many turns should be placed on the secondary to maintain its rated voltage at full load.

With this number of turns on the secondary and the primary voltage held constant, what is the secondary no-load voltage?

5. Advantages

① less I^2R losses in copper lines as the voltage is kept high while current is kept low for a given Kilowatt load.

② as voltage is high and current low, the copper lines can be of reduced diameter that otherwise wouldn't be the case, thus a substantial savings in the cost of transmission lines.

2400 / 240 V transformer

$N_1 = 2000\ t$

3% voltage drop at full load

$V/t = \frac{2400}{2000} = 1.2\ V/t$

$0.03(240) = 7.2\ V$

$7.2\ V / 1.2 = 6$ turns

$N_2 = 206$ turns

$V_{NO\ LOAD} = 206(1.2) = 247.2\ V$

42. For the “no-load” test on a transformer, the ammeter was found to read 0.18A and the wattmeter 12W. The reading on the primary voltmeter was 400V, and the secondary voltmeter was 240V. Calculate the following:

i. The magnetizing component of the “no-load” current
ii. The iron loss component
iii. The transformation ratio.

7. No load test

$I = 0.18\,A$

$W = 12\,W$

$V_1 = 400\,V$

$V_2 = 240\,V$

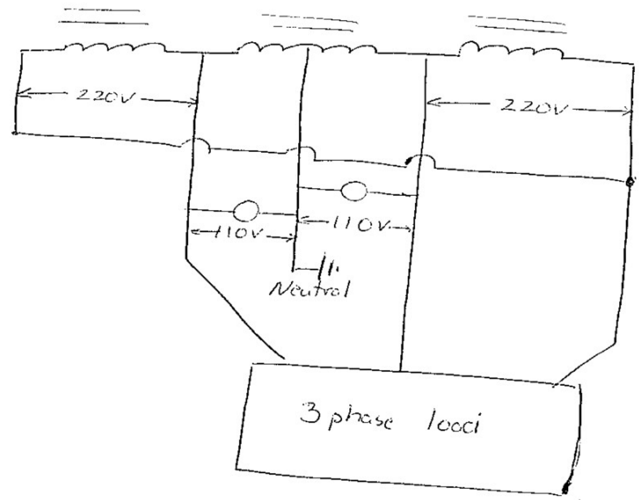
$$I_{Iron} = \frac{12\,W}{400\,V} = 0.03\,A$$

$$I_{MAG} = \sqrt{0.18^2 - 0.03^2} = \underline{\underline{0.177\,A}}$$

$$\alpha = \frac{V_1}{V_2} = \frac{400}{240} = \underline{\underline{1.67}}$$

43. Illustrate a three phase supply utilizing 220V for power purposes and 110V for lighting. If the loads are unbalanced, sketch a system that will accommodate the unbalance.

4.

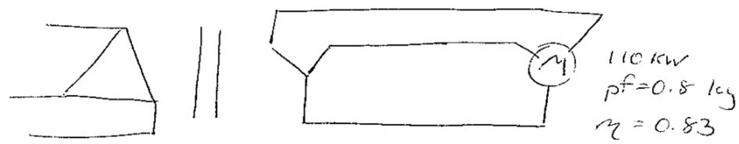


Three-Wire Edison System

- three phase loads can be connected across all phases
- single phase 220 V loads can be connected between phases
- a center-tap neutral wire can be taken from one phase to accommodate 110 V single phase loads
- for unbalanced loads, unbalanced currents will flow in the neutral wire, but power and lighting loads will be maintained at proper levels

44. A delta primary and star secondary transformer of 200KVA capacity has a primary voltage of 6600 secondary voltage of 440V, 3 phase. If the transformer is loaded with a 110kW motor that takes $440V \quad 60Hz$ with P.F. of 0.8 and efficiency of 83%, find the phase current in the primary.

3. 6600 / 415 200 KVA



For Y, $I_L = I_{ph}$

$I_{ph2} = \underline{\underline{230.47 A}}$ in secondary

For Δ, $I_L = \sqrt{3}\, I_{ph}$

$I_{ph1} = \underline{\underline{8.37 A}}$ in primary

$P_{Motor} = \dfrac{110\ kW}{0.8(0.83)} = 165.66\ KVA$

$P = \sqrt{3}\, V_L I_L$

$I_L = \dfrac{165.66\ KVA}{\sqrt{3}\,(415)}$

$= \underline{\underline{230.47 A}}$

<u>For primary</u>

$165.66\ KVA = \sqrt{3}\,(6600)\, I_L$

$I_{L1} = \underline{\underline{14.49 A}}$

45. A 6-pole three phase $550V,\ 60HZ,$ induction motor has 5% slip and draws a current of 30A when delivering a shaft torque of 150Nm. Assume windage and friction losses amount to a torque of 10Nm and the iron copper loss at 900W. calculate the following:

i. Motor speed
ii. Brake power
iii. Input power
iv. Power factor
v. Efficiency

4. 6 pole, 3 phase

$V = 550\ v$

$f = 60\ Hz$

$S = 5\ \%$

$I = 30\ A$

$T = 150\ Nm$

losses

$T = 10\ Nm$ windage + friction

$P_{STATOR} = 900\ w$

$N_{sync} = \frac{120f}{P} = \frac{120(60)}{6} = 1200\ rpm$

$N_{Actual} = 0.95(1200) = \underline{\underline{1140\ rpm}}$

$P_{brake} = T \cdot \omega$

$= (150)\, 2\pi \left(\frac{1140}{60}\right)$

$= \underline{\underline{17.907\ kw}}$

$\frac{\text{Rotor Cu loss}}{\text{Rotor output}} = \frac{s}{1-s} = \frac{0.05}{0.95} \approx$

$P_{Cu} = \frac{0.05}{0.95}(19.1\ kw) = \underline{\underline{1.005\ kw}}$

$P_{out} = T \cdot \omega$

$= (150+10)\, 2\pi \left(\frac{1140}{60}\right)$

$= \underline{\underline{19.1\ kw}}$

$P_{IN} = 19.1\ kw + 1.005\ kw + 0.9\ kw$

$= \underline{\underline{21.0\ kw}}$

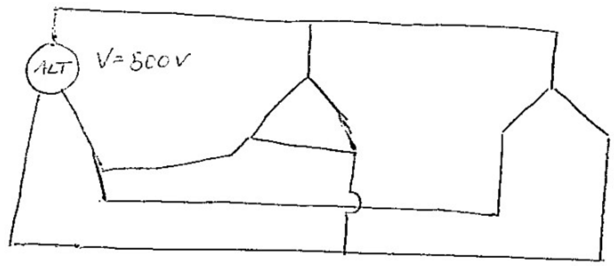
$pf = \frac{P_{TRUE}}{P_{Apperent}} = \frac{21.0\ kw}{\sqrt{3}(550)(30)}$

$= \underline{\underline{0.735\ lag}}$

$\eta = \frac{19.1\ kw}{21.0\ kw} = \underline{\underline{90.95\ \%}}$

46. A 500V three phase alternator supplies a balanced delta connected load in parallel with a balanced star connected load. The delta load is 30kW at a power factor of 0.92 (leading). The star load is 40kW at a power factor of 0.85 (lagging). Calculate the line current and the power factor of the supply.

2.

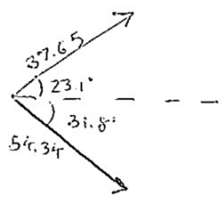


30 kW
pf = 0.92 lead
$\theta = 23.1^\circ\ (+)$

40 kW
pf = 0.85 lag
$\theta = 31.8^\circ\ (-)$

$$I_{L\Delta} = \frac{30000}{\sqrt{3}(500)(0.92)} = 37.65A \angle 23.1^\circ$$

$$I_{L\curlywedge} = \frac{40000}{\sqrt{3}(500)(0.85)} = 54.34A \angle -31.8^\circ$$



$$I_x = 37.65 \cdot \cos 23.1^\circ + 54.34 \cos -31.8^\circ = 80.8\,A$$

$$I_y = 37.65 \sin 23.1^\circ + 54.34 \sin -31.8^\circ = -13.86\,A$$

$$I_R = \sqrt{80.8^2 + 13.86^2} = 81.98\,A$$

$$\theta = \tan^{-1}\left(\frac{-13.86}{80.8}\right) = -9.73^\circ$$

pf = 0.986 lag

47. A 3-phase $440V \quad 60HZ$, six-pole induction motor develops 18kW on full load with a speed of 1164RPM and operating power factor of 0.88 (lagging). Calculate the full load:

i. Slip
ii. Input in kW
iii. Line current

The stator losses are 1.7kW and mechanical losses total 1.5kW

1. $P_{OUT} = 18\ kW$ $\quad P_{STATOR} = 1.7kW$

6 poles $\quad P_{MECH} = 1.5\ kW$

$N_{RUN} = 1164$ $\quad pf = 0.88\ lag$

$V = 440V$

$f = 60\ Hz$

$$N_{sync} = \frac{120f}{P} = \frac{120(60)}{6} = \underline{\underline{1200\ rpm}}$$

$$\%\ slip = \frac{1200 - 1164}{1200} = \underline{\underline{3\%}}$$

$$P_{in} = 18 + 1.5 + 1.7$$
$$= \underline{\underline{21.2\ kW}}$$

$$P = \sqrt{3}\ V_L I_L \cos\theta$$

$$21.2\ kW = \sqrt{3}(440)\ I_L\ (0.88)$$

$$I_L = \underline{\underline{31.6\ A}}$$

48. A 3 phase, 6.6kV 60HZ alternator has an equivalent armature reactance of 5ohms per phase and negligible resistance. It is connected to bus bars which are energized by a second identical alternator. The breaker is closed when both armatures are rotating at 1800 RPM but 2 electrical degrees out of phase:

i. synchronizing current
ii. Synchronizing torque

2. E_1 = Voltage of machine on bus
E_2 = Voltage of incoming

$$V_{ph} = \frac{6600}{\sqrt{3}} = 3810.5\,V$$

$$E_r = 2E \cdot \sin\frac{\theta}{2}$$
$$= 2(3810.5)\sin(2/2)$$
$$= 133.0\ V$$

$$I_{sync} = \frac{E_r}{2 \cdot X_{ph}} = \frac{133.0}{2 \cdot 5} = 13.3\,A$$

$$P_{sync} = E_2 \cdot I_s \cos\theta/2$$
$$= (3810.5)(13.3)\cos 2/2$$
$$= 50.67\,kW$$

$$\text{Total power} = 3(50.67\,kW)$$
$$= 152.0\,kW$$

$$P = T\omega$$

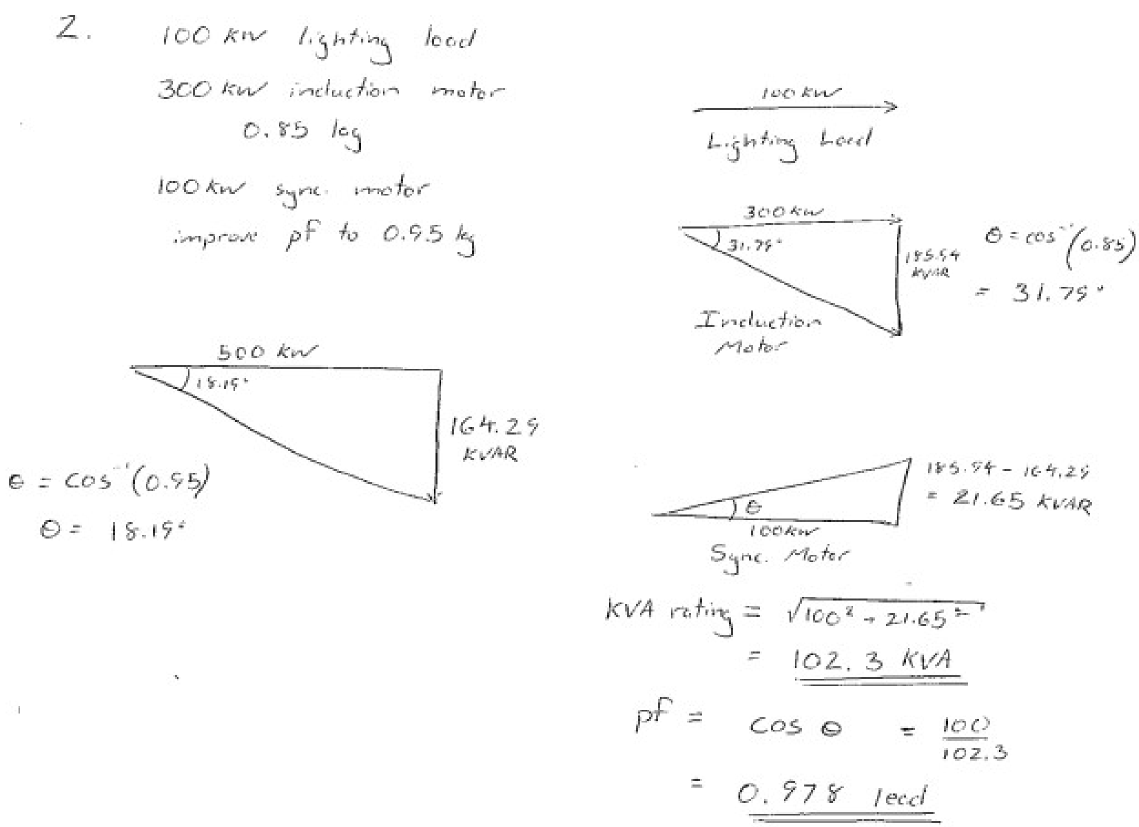
$$152.0\,kW = T \cdot 2\pi\frac{(1800)}{60}$$

$$T = 806.4\,Nm$$

49. An electrical system load consists of a 300kW induction motor power factor 85% and 100kW lighting with power factor 100%. It is proposed to increase the system power factor of 95% by employing a 100kW synchronous motor.

Find the following:

i. the KVA of the synchronous motor
ii. The power factor of the synchronous motor.



50. A shunt generator delivers 50kW at 250V at 400 RPM. The armature and field resistances are 0.02 ohm and 50 ohm respectively. Calculate the speed of the machine when running as a shunt motor taking 50kW at 250V. allow 2 volts for brush contact drop. Assume flux (ϕ) to be proportional to field current.

51. A fresh pump is found to take armature current of 25A at 220V, when running on full load. The speed is measured to be 725 RPM and the armature resistance is 0.2 ohm. If the field strength is reduced by 10% by means of the speed regulator and the torque remains unchanged, determine the steady speed ultimately attained and the armature current.

2.

$N = 725$ rpm

$R_A = 0.02\,\Omega$

$V_T = 440\,V$

$I_A = 25\,A$

$\Phi_2 = 0.9\,\Phi_1$

$T_2 = T_1$

$E_{BACK\,1} = 440 - 25(0.02) = \underline{439.5\,V}$

$T_1 = T_2$

$K\Phi I_{A1} = K\Phi I_{A2}$

$\Phi_1 \cdot (25) = 0.9\,\Phi_1 (I_{A2})$

$I_{A2} = \underline{\underline{27.78\,A}}$

$E_{BACK\,2} = 440 - 27.78(0.02) = \underline{439.4\,V}$

$$\frac{E_{BACK\,2}}{E_{BACK\,1}} = \frac{K\Phi_2 N_2}{K\Phi_1 N_1}$$

$$\frac{439.4}{439.5} = \frac{0.9\,N_2}{725} \qquad N_2 = \underline{\underline{805.4 \text{ rpm}}}$$

52. Find the generated electro magnetic field per conductor of a 6-pole D.C. generator having a magnetic flux per pole of 64 mWb and a speed of 1000 rpm. If there are 468 conductors, connected in six parallel circuits, calculate the total generated EMF of the machine. Find also the total power developed by the armature when the current in each conductor is 50A.

2.

$P = 6$ poles

$\Phi = 0.064$ wb

$N = 1000$ rpm

$Z = 468$

$I = 50A$

$A = 6$

$$E = \frac{P \Phi N Z}{60 A}$$

$$= \frac{6(0.064)(1000)(468)}{60(6)}$$

$$= 499.2 V$$

$$P = I \cdot V$$

$$= (50A)(6)(499.2)$$

$$= 149.76 kW$$

53. A D.C. shunt motor is wave wound and has four poles. The flux per pole is 2.5×10^{-2} *weber*. Armature current is 20A. Supply voltage is 230V. Conductors 294. Armature resistance 0.35 ohm. Calculate the RPM and torque.

5.

$V_T = 230V$

$Z = 294$ conductors

$\Phi = 1 \cdot 10^{-2}$ wb

$P = 4$

$I_A = 200A$

$R_A = 0.35\ \Omega$

wave wound $A = 2$

$E_{back} = 230 - 200(0.35)$

$= \underline{160V}$

$$E = \frac{P \Phi N Z}{60A}$$

$$160 = \frac{4(1 \cdot 10^{-2}) N (294)}{60(2)}$$

$N = \underline{1632.65 rpm}$

$P = T \cdot \omega$

$$T = \frac{160(200)(60)}{1632.65(2\pi)} = \underline{187.17\ Nm}$$

54. The curve of induced e.m.f. against excitation current for a separately excited generator when run on no load at 1200 RPM is given by:

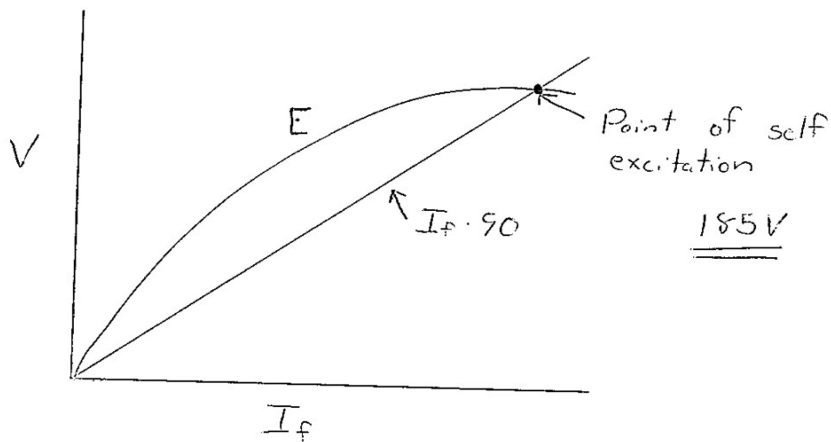
E.M.F	15	88	146	196	126	244	254
Excitation Current	0	0.4	0.8	1.2	1.6	2.0	2.4

Deduce the voltage to which the machine would self-excite if the shunt field resistance was set at 90 ohms and the machine was run at 900 RPM.

2.

I	0	0.4	0.8	1.2	1.6	2.0	2.4
E(1200)	15	88	145	196	226	244	254
E(900)	11.25	66	108.75	147	169.5	183	190.5

Since $E = N \cdot \frac{\Phi}{k}$ $\quad E \propto N$ $\quad \frac{E_{900}}{E_{1200}} = 3/4$



55. A four pole shunt motor has a wave wound armature having 294 conductors. The flux per pole is 0.025 Wb. And the resistance of armature is 0.35 ohm. Calculate the following:

I. current taken by motor
II. torque develop when armature is taking a current of 200A from 200V supply

3. $P = 4$ poles

wave wound $A = 2$

$Z = 298$ conductors

$R_A = 0.35\,\Omega$

$\Phi = 0.025$ Wb

$I_A = 200\,A$

$V_T = 200\,V$

$$E_{back} = 200 - 200(0.35)$$
$$= 130\,V$$

$$E = \frac{P\Phi NZ}{60A}$$

$$130 = \frac{4(0.025)N(298)}{60(2)}$$

$$N = 523.5 \text{ rpm}$$

$$P = T \cdot \omega$$

$$130(200) = T\left(\frac{523.5}{60}\right)2\pi$$

$$T = 474.3 \text{ Nm}$$

56. A pump delivers 12700 litres per hour of water into a boiler working at 15 bars. The pump is 82% efficient and is driven by a 220V motor, having an efficiency of 89%.

Calculate the current taken by motor.

Given the following: $1\ Litre\ of\ water = 1\ kg$

$1\ Bar = 10^5\ N/m^2$

2. Height of water $= \dfrac{P}{\rho g} = \dfrac{15 \cdot 10^5}{(1000)(9.81)}$

$= 152.905\ m$

$F = (12700\ kg)(9.81\ N/kg)$

$= 124587\ N$

$P = \dfrac{F \cdot d}{t} = \dfrac{(124587)(152.905)}{3600} = 5.292\ kW$

Motor output $= \dfrac{5.292\ kW}{0.82} = 6.454\ kW$

Motor input $= \dfrac{6.454\ kW}{0.89} = 7.252\ kW$

Motor current $= \dfrac{P}{V} = \dfrac{7.252 \cdot 10^3\ W}{220\ V}$

$= 33.0\ A$

57. A shunt motor operates at 1200 rpm and the supply voltage is 220V. the current is 60A, the shunt field resistance is 110 ohms and the armature resistance 0.15 ohm. What percentage variation in speed will there be if torque is reduced to 50%?

6.

$N_1 = 1200$ rpm

$V_T = 220$ V

$I = 60$ A

$R_S = 110\ \Omega$

$R_A = 0.15\ \Omega$

$T_2 = 0.5\,T_1$

$$I_S = \frac{220V}{110\Omega} = 2A$$

$$I_{ARM} = 60 - 2 = \underline{58A}$$

$$E_{back\,1} = 220 - 58(0.15) = \underline{211.3\ V}$$

$$T = \frac{E_b \cdot I_A}{\omega} \qquad \omega = \frac{2\pi N}{60}$$

$$T_1 = \frac{211.3(58)(60)}{2\pi(1200)} = \underline{97.53\ Nm}$$

$$\frac{T_2}{T_1} = \frac{K\Phi_2 I_{A2}}{K\Phi_1 I_{A1}}$$

$$\frac{0.5\,T_1}{T_1} = \frac{I_2}{58}$$

$$I_{A2} = \underline{29A}$$

$$T_2 = 0.5(97.53) = \underline{48.765\ Nm}$$

$$T_2 = \frac{E_{b2} \cdot I_{A2}}{\omega}$$

$$E_{back\,2} = 220 - 29(0.15) = \underline{215.65\ V}$$

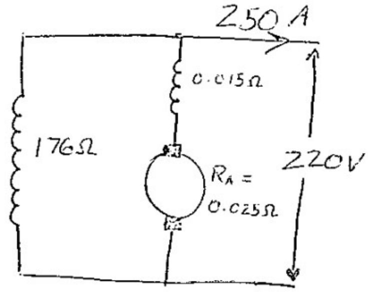
$$48.765 = \frac{215.65(29)(60)}{2\pi\ N_2}$$

$$N_2 = \underline{1224.65\ rpm}$$

$$\%\ variation = \frac{1224.65 - 1200}{1200} = \underline{2.05\ \%}$$

58. A compound wound long shunt DC generator has output of 250A at 220V. the equivalent resistance of armature, series and shunt fields are 0.025, 0.015 and 176 ohms respectively. There is a 2 volt drop across the brushes. Find the induced voltage.

6.



$V_{Brushes} = 2\ V$

$I_{SHUNT} = \frac{220V}{176\ \Omega} = 1.25\ A$

$I_{ARM} = 250 + 1.25$
$= 251.25\ A$

$E = 220 + 251.25(0.015 + 0.025) + 2$
$= 232.05\ V$

59. A 460V D.C. motor takes an armature current of 10A at no lead. At full load the Ia is 300A. If the resistance of the armature (Ra) is 0.025 ohm, what is the value of the back e.m.f at "no load" and "full load".

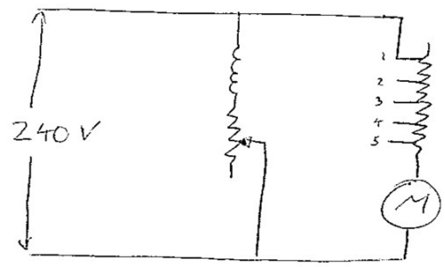
8.
$V_T = 460\ V$
$I_{NL} = 10\ A$
$I_{FL} = 300\ A$
$R_A = 0.025\ \Omega$

$E_{BACK\ NL} = 460 - 10(0.025)$
$= 459.75\ A$

$E_{BACK\ FL} = 460 - 300(0.025)$
$= 452.50\ A$

60. Determine the resistance of each step of a starter for the following motor: 10h.p. 240V, armature resistance 0.5 ohm and full load current limited to 45 amperes. Starting current to be 150% of full load current.

9.



$R_a = 0.5\ \Omega$

$I_{FL} = 45\ A$

$I_{ST} = 1.5(45) = \underline{67.5\ A}$

$R_T = \frac{240}{67.5} = 3.56\ A$

$R_1 = 3.56 - 0.5$
$= \underline{3.06\ \Omega}$

$E_{BACK\ 1} = 240 - 45(3.56)$
$= 79.8\ V$

$240 = 79.8 + 67.5(R_2 + 0.5)$

$R_2 = 1.87\ \Omega$

$E_{BACK\ 2} = 240 - 45(2.37)$
$= 133.35\ V$

$240 = 133.35 + 67.5(R_3 + 0.5)$

$R_3 = 1.08\ \Omega$

$E_{BACK\ 3} = 240 - 45(1.58)$
$= 168.9\ V$

$240 = 168.9 + 67.5(R_4 + 0.5)$

$R_4 = 0.55\ \Omega$

$E_{BACK\ 4} = 240 - 45(1.05)$
$= 192.75\ \Omega$

$240 = 192.75 + 67.5(R_5 + 0.5)$

$R_5 = 0.2\ \Omega$

$R_{STEP\ 1} = 3.56\ \Omega$

$R_{STEP\ 2} = 2.37\ \Omega$

$R_{STEP\ 3} = 1.58\ \Omega$

$R_{STEP\ 4} = 1.05\ \Omega$

$R_{STEP\ 5} = 0.7\ \Omega$

61. Illustrate the construction of an induction motor. Describe how it operates and explain the difference between it and a synchronous motor.

3. Squirrel Cage Construction

- stator core built of slotted steel laminations supported in a stator frame of cast iron or steel plate.
- windings are spaced 120° apart in the stator slots
- phase windings may be Y or Δ connected.

- rotor is a laminated core with the conductors placed parallel to the shaft & embedded in the core surface
- conductors not insulated from core
- at each end, conductors are short-circuited by continuous end rings.

Wound-Rotor Motor Construction

- rotor is wound with an insulated winding similar to stator winding
- phase windings are Y connected with open end of each phase brought out to slip ring mounted on rotor shaft

Principle of Operation

- as rotating magnetic field sweeps across rotor conductors, an emf is induced in the conductors.
- induced emf causes current to flow in rotor conductors
- as a result, these conductors have force exerted upon them, tending to turn the rotor.
- motor will accelerate if developed torque is greater than resisting torque.

62. Discuss the functions of the following elements of an automatic voltage regulator for an alternator.

a. Error detecting element
b. Correcting element
c. Stabilizing element

1. ① Error sensing element

- puts the regulating elements into action as soon as there is "error" in the system
- correction cannot be applied until there is a departure from the normal operating voltage
- also includes a "reference" component which establishes the value of voltage it is desired to maintain

② Corrective element

- element that makes changes which will determine the necessary amount of correction.
- converts the information from the voltage comparison circuit into a control signal which is suitable for actuating the control element

③ Stabilizing Element

- element which prevents "hunting" or "oscillating" and overcorrection
- purpose is to control sharing of KVA load between generators operating in parallel.

63. Discuss a synchronous motor. State the two main functions of the damper winding.

2. Operation of Synchronous Motor

- rotating magnetic field set up by the stator windings cuts across squirrel cage winding of rotor
- voltages and currents are induced in bars of this windi-
- magnetic field set up in squirrel cage
- this field reacts with stator field and causes rotation of rotor.
- speed of rotor increases until just below synchronous speed of stator Field (about 95% of sync speed)
- when rotor at maximum speed, the DC excitation is turned on to lock the rotor into the rotating magnetic field.
- field discharge resistor used on starting & stopping
  starting → discharge induction energy when starting
  stopping → activates when DC field is removed
- synchronous motor is inherently not self starting
- damper winding used for starting and reduction of hunting that would occur with load changes.

8 pole motor

$$N_{50} = \frac{120f}{P} = \frac{120(50)}{8} = \underline{\underline{750 \text{ rpm}}}$$

$$N_{60} = \frac{120(60)}{8} = \underline{\underline{900 \text{ rpm}}}$$

64. Describe frequency as pertinent to AC. A four pole AC generator runs at 1500 RPM; what is it's frequency? If this generator supplies current to a 40 pole motor, find the speed of the motor:

a. If it is synchronous
b. If induction with slip of 2%

5. Frequency as pertinent to A.C. is the relationship between the number of sine wave cycles of voltage or current that occur in one second.

The symbol for frequency is Hz. 60 Hz means 60 complete sine wave cycles is occuring every second.

$$f = \frac{PN}{120} = \frac{4(1500)}{120} = \underline{\underline{50\ Hz}}$$

Sync. Motor $N = \frac{120 f}{P} = \frac{120(50)}{40} = \underline{\underline{150\ rpm}}$

Induction Motor $N = \frac{0.98(120)(50)}{40} = \underline{\underline{147\ rpm}}$

65. A six pole three phase 50 HZ induction motor is running at full load with a slip of 4%. The rotor is star connected and its resistance and standstill reactance are 0.25 ohm and 1.5 ohms respectively. The E.M.F. between the slip rings at standstill is 100V.

Find the full load conditions:

I. The e.m.f. induced in each motor phase
II. The motor impedance per phase
III. The rotor current and PF assuming the slip rings are short circuited.

Z. 6 pole, 3 ph — star connected rotor

$f = 50\,Hz$ — $R = 0.25\,\Omega$

$S = 4\%$ — $X = 1.5\,\Omega$

$V = 100\,V$

V_{ph} at standstill $= \frac{100}{\sqrt{3}} = \underline{\underline{57.7\,V}}$

E_{ph} at full load $= 57.7(0.04)$

$= \underline{\underline{2.308\,V}}$

Rotor reactance $= X_{ph} = 1.5(0.04)$

$= \underline{\underline{0.06\,\Omega}}$

$Z = \sqrt{0.25^2 + 0.06^2}$

$= \underline{\underline{0.257\,\Omega}}$

$V = IZ$

$2.308 = I(0.257)$

$I = \underline{\underline{8.98\,A}}$

$pf = \frac{R}{Z} = \frac{0.25}{0.257} = \underline{\underline{0.97 \text{ lag}}}$

66. Find the line current for a 440V 3-phase motor which is 88% efficient and is rated at 110kW. Current lags the voltage by 30 degrees.

1. Motor output = 110 kW

$\eta = 88\%$

$V = 440V$

$\theta = 30°$ lag

$pf = 0.866$

$$P_{in} = \frac{110}{0.88} = 125 \text{ kW}$$

$$P = \sqrt{3} V_L I_L \cos\theta$$

$$I_L = \frac{125000}{440(0.866)(\sqrt{3})}$$

$$= 189.40 \text{ A}$$

67. A four pole alternator on open circuit generates 200V at 50 HZ when its field current is 4A Determine the generated e.m.f. at a speed 1200 RPM and a field of 3A neglecting saturation of the iron parts.

3. $P = 4$

$V = 200V$

$f = 50 Hz$

$I_F = 4A$

$N = 1200$ rpm

$I_F = 3A$

$$f = \frac{PN}{120}$$

$$N = \frac{120(50)}{4}$$

$$= 1500 \text{ rpm}$$

Using $E \propto KNI$

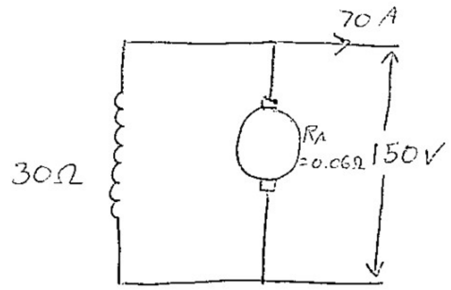
$$\frac{E_1}{E_2} = \frac{KN_1 I_1}{KN_2 I_2}$$

$$\frac{200}{E_2} = \frac{1500(4)}{1200(3)}$$

$$E_2 = 120 V$$

68. The terminal voltage of a shunt wound generator is 150volts and the current output is 70 amperes. If the resistance of the field windings is 30 ohms and that of the armature conductors is 0.06 ohm, calculate the electrical efficiency of the generator.

3.



$$I_{Shunt} = \frac{150V}{30\Omega} = 5A$$

$$I_{ARM} = 70 + 5 = 75A$$

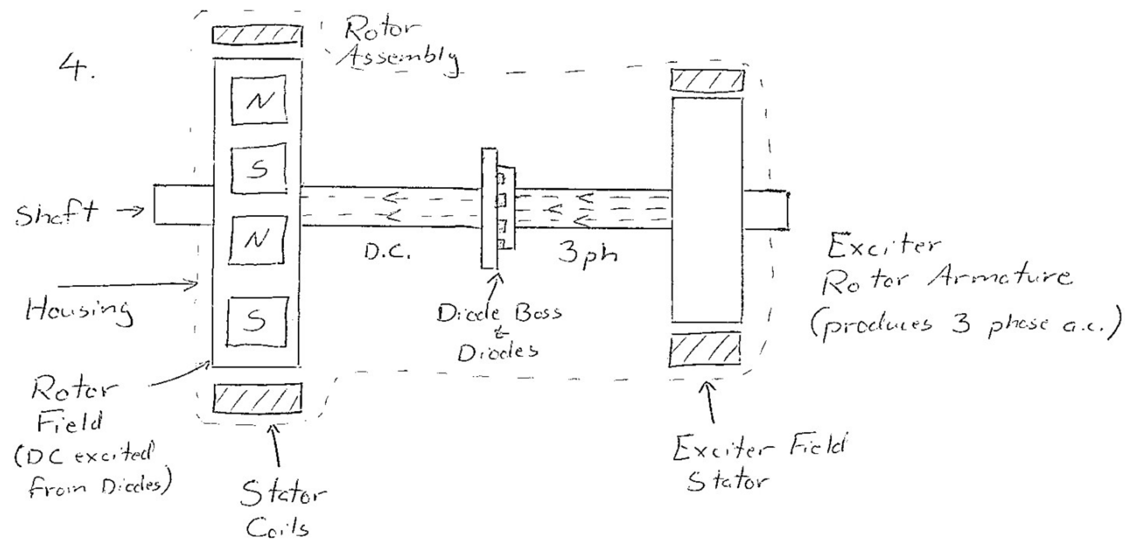
$$\eta = \frac{P_{OUT}}{P_{OUT} + P_{Field} + P_{ARM}} = \frac{150(70)}{150(70) + 75^2(0.06) + 5^2(30)}$$

$$= \frac{10500}{10500 + 337.5 + 750}$$

$$= 90.6\%$$

69. Sketch and describe a three phase alternator. Explain how to connect up two alternators in parallel, in particular state the procedure for synchronizing.

4.



- two windings → ① salient pole rotor on left
  ② exciter on right : receives induced voltage from stator exciter winding
- main stator winding wound on inside periphery of housing.
- brushless exciter → voltage induced in exciter rotor is rectified by the diodes and fed directly to main field rotor coils
- revolving field & stationary armature construction simplifies the problems of insulation
  - slip rings not needed to bring out voltages but insulated leads may be connected directly to the stationary armature.
  - windings are stationary so they are not subjected to as much vibration
- magnetic field produced by energizing the pole windings with direct current through a direct cable connection between the dc generator and rotating rectifier.

Paralleling

- conditions must be met
  1. same phase sequence
  2. equal terminal voltages
  3. voltages in phase
  4. equal frequencies

1. Ensure breaker for incoming is open
2. Switch voltage regulator to auto
3. Start generator and run up to speed
4. Use governor control and adjust frequency to match bus
5. Use voltage regulator to adjust voltage to match bus.
6. Adjust frequency slightly higher than bus
7. Turn synchroscope to incoming
8. Adjust frequency until scope is rotating slowly in fast direction.
9. Close CB for incoming when needle approaches 12 o'clock.
10. Use govenor controls of both generators to share kw load.
11. Adjust voltage control to equalize kvar load.
12. Turn synchroscope to "off".

70. An 8 pole alternator running at 720 RPM supplies current to a synchronous motor with 48 poles. Calculate the frequency and speed of rotation of the motor.

3.

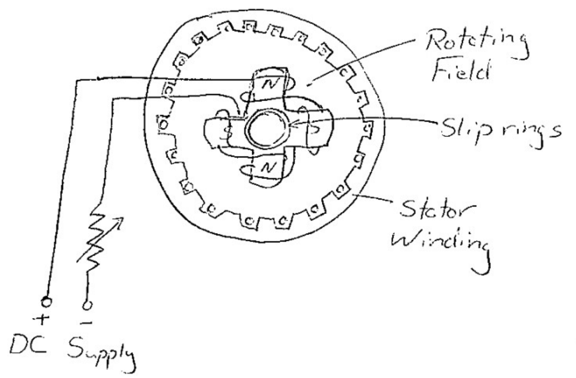
8 pole alternator
N = 720 rpm
48 pole motor

$$f = \frac{PN}{120} = \frac{8(720)}{120} = 48\ Hz$$

$$N = \frac{120f}{P} = \frac{120(48)}{48} = \underline{\underline{120\ rpm}}$$

71. Discuss the difference between a synchronous motor and induction motor. How is a synchronous motor started?

1.



- the stator construction is basically the same as that for an induction motor.
- built of slotted steel laminations.
- laminations supported in stator frame.
- winding spaced 120° apart (Y or Δ connection).

- rotor made of field poles which are seperately excited by DC current.
- copper squirrel cage assembly mounted on rotor poles to form composite rotor.

- squirrel cage or ammortisseur winding provided to get rotor into motion and, when up to speed, the seperately excited field poles are fed with DC and the rotor locks into the same speed of rotation as the rotating field. (synchronous speed)

Starting

① Armature (stator) is connected to the line.

② Field windings (rotor) connected to discharge resistor until rotor gets up to speed.

③ Started as "induction motor", as the rotating field of the stator cuts the squirrel cage winding of the rotor, which is fitted over the rotor.

④ As speed reached, field discharge resistor disconnected and the field is connected to variable DC supply

72. What causes overheating in a squirrel cage motor? Discuss the preventive maintenance required on this type motor.

1. Overheating of a SCIM

- causes:
  1. faulty bearings
  2. shorted or grounded stator windings
  3. inadequate ventilation (openings obstructed)
  4. mechanical overloading
  5. malfunction of centrifugal switch

- preventative maintenance:
  1. dissassemble annually and clean parts
  2. replace defective bearings
  3. check insulation of stator windings with megger
  4. ensure no breaks in squirrel cage
  5. if "capacitor start" type → check capacitor with tester or ohm meter to ensure high resistance
  6. check centrifugal switch assembly and ensure contacts are clean and operating freely.

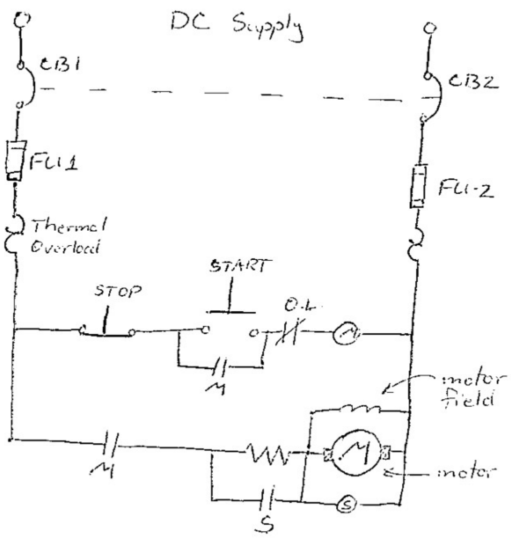
73. Define the following:

I. Current limit

II. Time limit acceleration

2. Current Limit

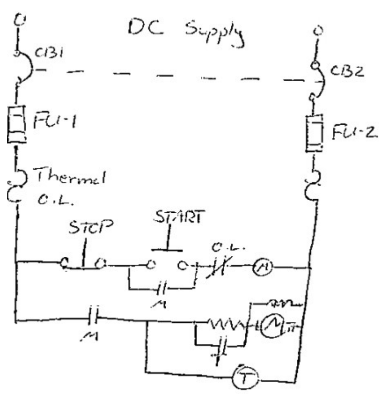
- term applied to DC motors which means that some method of limiting the current during starting is employed
- use relays to limit current
- current limit relay → those which will only operate when a certain level of current is passed through their coils



(S) - back emf contactor

→ Current through (S) increases with back emf and will eventually close -||- (S) to bypass current limiter.

Time Limit Acceleration



- term applied to DC starters which implies that the relays employed to successively reduce the resistance inserted in series w/ the armature will only operate after a definite time interval has passed.

(T) - timed close contactor

- contacts T close after set time to short out the starting resistor.

74. Describe a Magnetic Motor Starter for an AC three phase, two speed motor. (full voltage). Illustrate the answer with a simple circuit diagram. Show the protection devices, control station, contactors and coils.

75. A DC starter is used for a shunt wound motor utilizing 230V. If the armature resistance is 0.6 ohm and the maximum current permissible is 50 amperes and minimum of 40 amperes: find the first resistance

7.

$V_T = 230\ V$

$R_A = 0.6\Omega$

$I_{MAX} = 50A$

$I_{MIN} = 40A$

Initially, no back emf

$R_T = \frac{230}{50} = 4.6\ \Omega$

$R_{START\ 1} = 4.6 - 0.6$

$= \underline{\underline{4.0\Omega}}$

$E_{back\ 1} = 230 - 40(4.6)$

$= 46\ V$

$V_T = E_{back} + 50(R_{START2})$

$230 = 46 + 50\ R_{T2}$

$R_{T2} = 3.68\Omega$

$R_{START\ 2} = 3.68 - 0.6$

$= \underline{\underline{3.08\Omega}}$

$R_{START\ STEP\ 1} = 4.0 - 3.08$

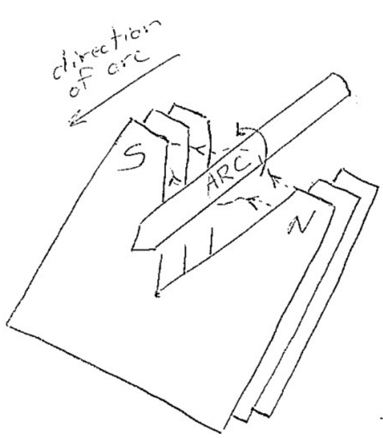
$= \underline{\underline{0.92\Omega}}$

76. Describe an "air circuit breaker". Sketch and describe an "arc chute". Define "reverse power relay".

7. a) Air Circuit Breaker

- one in which contacts are exposed to the air
- made in various frame sizes but construction generally the same
- rated at 500 VAC or 250 V DC
- generally 250, 600, or 1600 A
- consists of rigid steel chasis mounted on rails
  - ↳ may be withdrawn from switchboard
- basic elements
  - manually operated switch
  - thermally operated O/L trip mechanism
  - fast acting fuses
  - arc quenching device
- sub assemblies that may be mounted as components of the breaker
  - mechanical contact assembly
  - arc chutes
  - overcurrent trip devices
  - reverse power relay device
  - undervoltage release.

b) Arc Chute



- used to provide quick quench of any arc that is present between contacts in circuit breaker
- current of the arc develops its own magnetic field
- this field induces a field in the metal "V" shaped arc chute plates
- interaction between these fields causes a deflection of the arc downward into the V of the plates
- arc is split into a series of smaller arcs, where it is cooled and extinguished.

Reverse Power Relay

- Marine Safety Electrical Standards
  → each ac gen. operating in parallel shall be provided with a reverse power relay with time-lag to prevent the tripping of circuit breakers during switching operations. The relay must be suitable for tripping between the limits of 2% and 15% of full load.

- necessary to prevent generator from motorizing
- time delay and trip point incorporated to prevent tripping due to power surges
- normally manually reset with a pushbutton

- mainly a conventional ac wattmeter
- voltage and current coils create magnetic fields which induce currents in the aluminum disc.
- disc currents produce magnetic field which interacts with voltage and current magnetic fields and causes disc to rotate
- if disc turns in proper direction, everything runs as normal.
- if generator starts to run as motor, disc reverses its direction and operates a trip mechanism.
- mechanism has contacts that will open and de-energize the circuit breaker, removing the generator from the bus.

77. Define each of the following terms as related to an AC motor starter enclosure.

a. Disconnect
b. Short circuit protection
c. Overload protection
d. Start/stop control

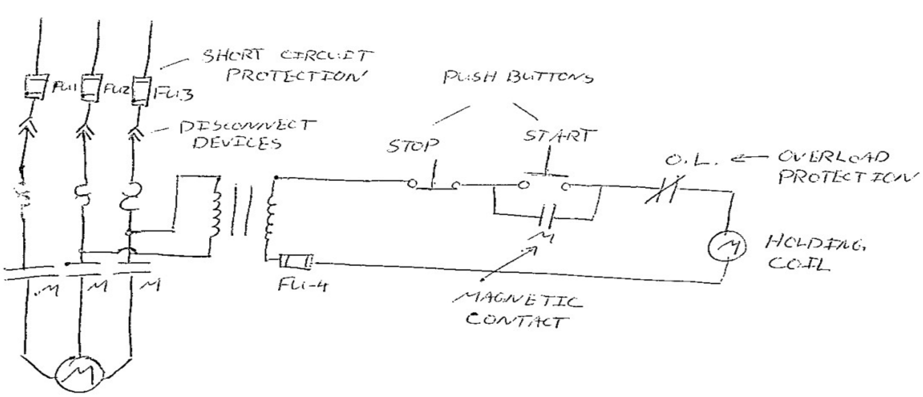
Draw a simple diagram of a 3 phase AC motor starting circuit which embodies.

a) Disconnect → a device or group of devices, or other means whereby the conductors of a circuit can be disconnected from their supply.

b) Short Circuit Protection → installed in the same enclosure as the disconnect. Devices such as fuses and circuit breakers are used to protect the motor branch circuit conductors, the motor control apparatus, and the motor itself against sustained overcurrent due to short circuits and grounds, and prolonged and excessive starting currents.

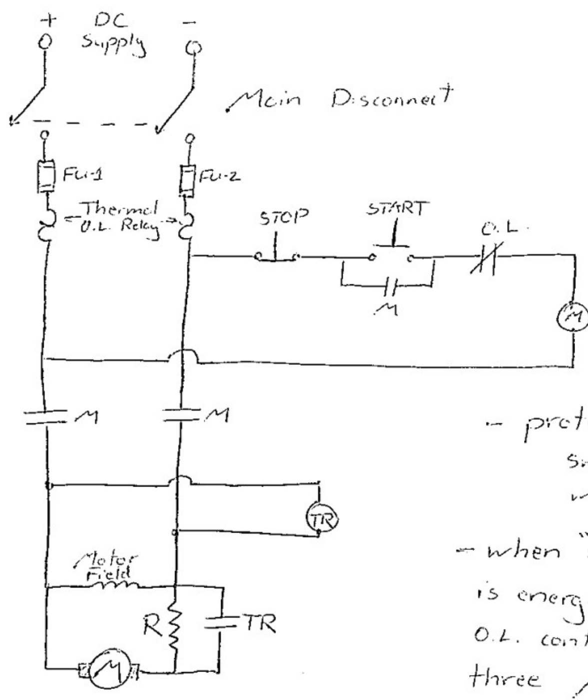
c) Overload Protection → overload means a current that is in excess of six times the rated current for an AC motor. It is protected by a device which operates on excessive current to cause the interrupter of current flow to the device being governed. It may be an integral or separate part of the motor.

d) Start/Stop Control – push buttons that are pressed to either start or stop the motor.



78. Sketch a DC. Shunt motor Automatic Starter showing all protection devices, etc. it should incorporate a time limit acceleration application. Explain it's operation.

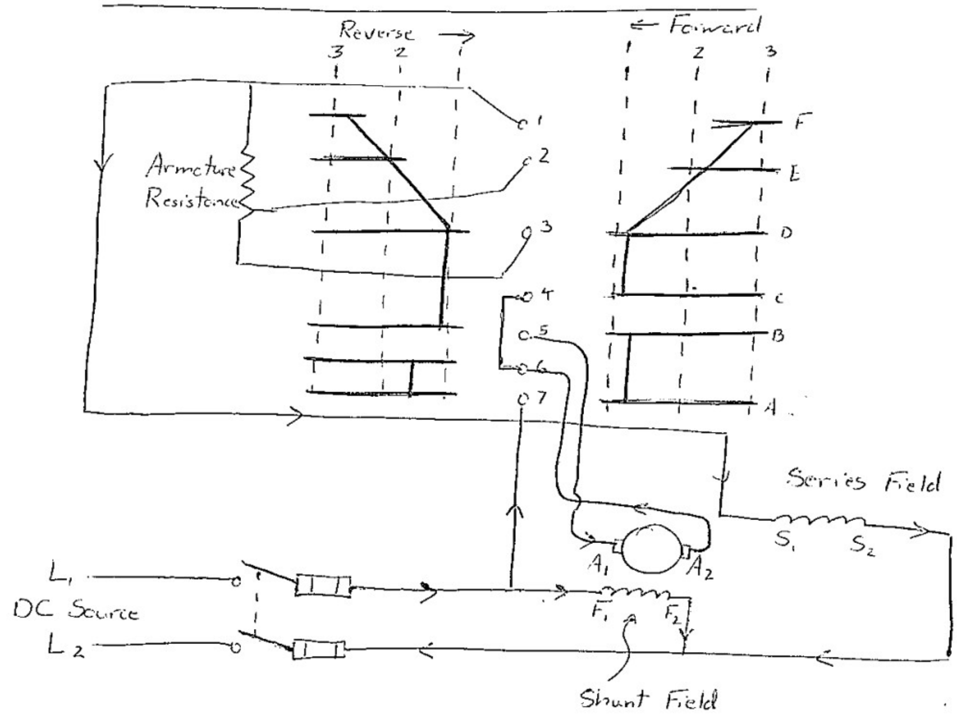
5. Automatic D.C. Motor Starter



- protective devices → main disconnect switch, fuses, thermal elements which trip O/L contacts.
- when "start" pressed, main holding coil is energized through stop button and O.L. contacts. M coil closes all three M contacts. One M contact is to main power in the control circuit and the other two to allow power to the power circuit.
- current passes through R to reduce voltage across the motor and timing relay starts
- as motor starts slowly, TR coil is counting and will close the TR contacts, after a set time, to bypass R and allow full voltage across the armature.
- when stop button is pressed, all contacts open and the motor supply is cut off allowing the motor to stop.

79. Describe the functions of a DC motor manual drum controller. Illustrate your answer with a simple circuit diagram.

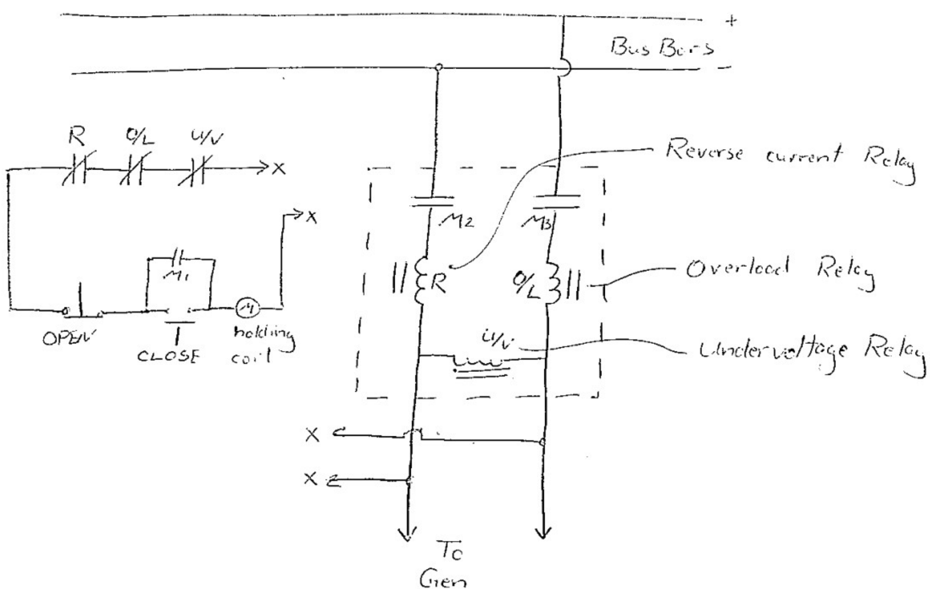
DC Motor Manual Drum Controller



- manual motor controller
- control arm can be rotated either CW or CCW
- contact assembly moves either to left or right
- in forward → L1 connected to A1, via contact 7, drum contact 5.
- in reverse → L1 connected to A2, via contact 7, drum contact 6.
- direction of motor is reversed by reversing the contacts to the armature.

80. Describe a circuit breaker as fitted on the electrical switchboard in the engine room of a ship; and explain how it functions. Illustrate your answer with a sketch.

6. Circuit Breaker on a DC Switchboard



- when CLOSE pressed, circuit is completed to main holding coil and energized closing the M contacts
- M_1 is a holding contact, M_2 & M_3 allow the generator to connect to the bus

- overload relay will operate when generator is overloaded
- cause break in control circuit and cuts power to the holding coil and removes the generator from the bus

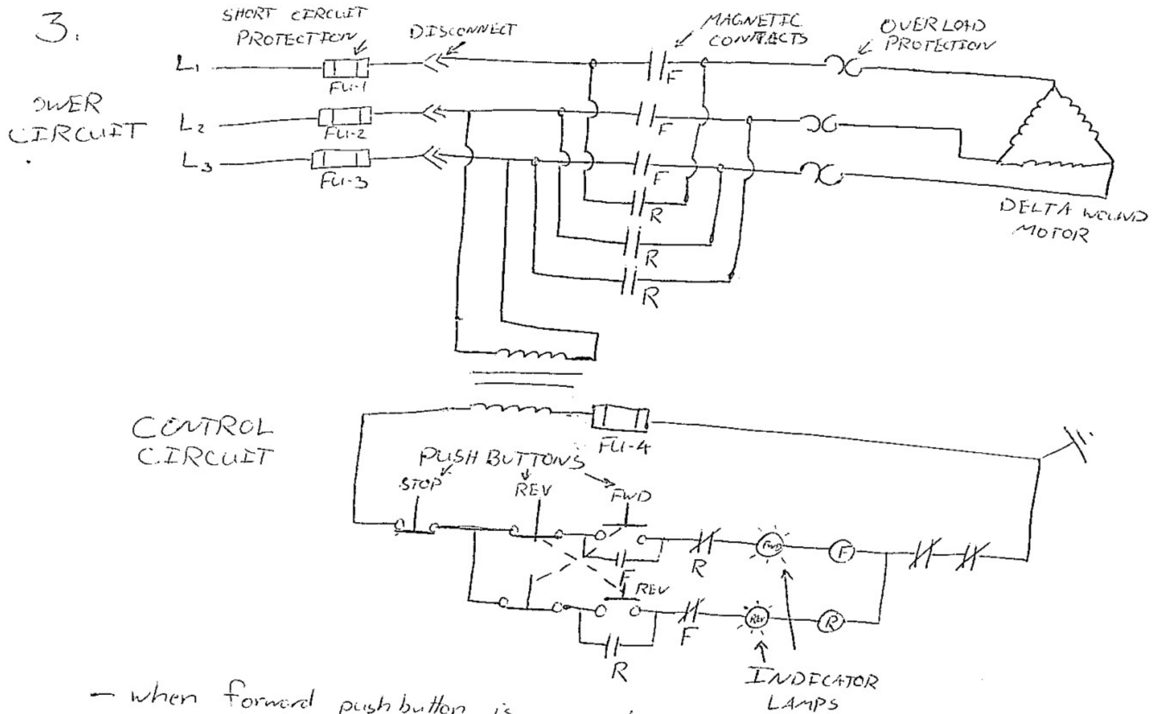
- undervoltage relay will operate if generators voltage output is reduced or if the bus bar voltage drops
- when operated, holding coil loses power and M contacts open
- reverse current relay will operate if generator starts to operate as a motor
- if voltage drops slightly (not enough for U/V), the reverse current relay will remove the generator from the bus.

81. Draw a simple circuit diagram for a 3 phase AC motor incorporating the following:

I. Motor delta wound
II. Overload protection
III. Short circuit protection
IV. Disconnect
V. Reversing
VI. Magnetic contactors
VII. Push button stn.
VIII. Indicator lamps

State the sequence of operation when forward and reverse buttons are pushed. What protection is provided against the possibility of pushing the forward and reverse buttons at the same time?

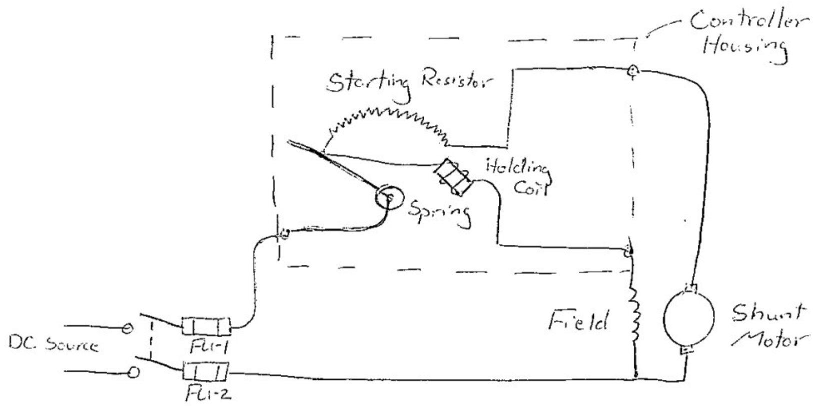
3.



- when forward push button is pressed, the forward contacts close allowing power flow to the motor. Reverse branch of circuit is opened by means of a normally closed forward contact.
- when reverse push button is pressed, a mechanical linkage between the buttons stops the motors in the forward direction and forward contacts return to normal state. Reverse contacts will close to allow power flow to the motor in a reversing direction.
- methods to prevent forward and reversing contacts closing at same time are mechanical interlocks between the pushbuttons and normally closed forward and reverse contacts.
- when stop button is pushed, all power is lost to the control circuit and all contacts return to at rest position.

82. Sketch and describe a 3 terminal rheostat type starter for a DC.

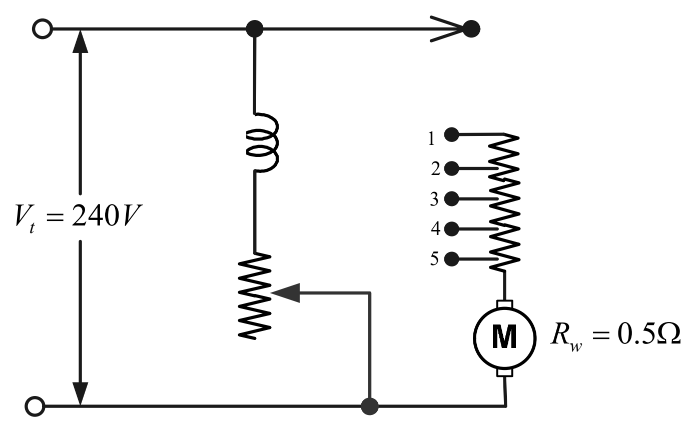
4/7 Manual DC Starter



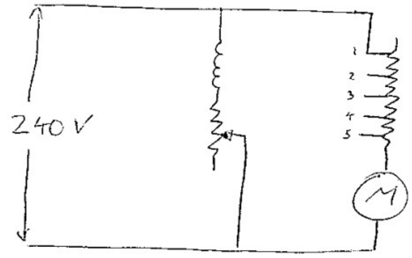
Operation – in the operation of this starter, the resistance is gradually cut out as the motor gains speed. As the motor gains speed, its back emf builds up and this takes over as a limiting feature to the armature current. The amount of starting resistance is manually removed and the holding coil holds the start lever in place once at full speed.

Reason for use ⇒ when the motor armature is at rest, the armature resistance is very small and with full voltage applied, the armature current would be very high. A high current would cause excessive heat and damage the armature. Once at speed, the back emf would limit the armature current.

83. In the sketch shown, determine the resistance of each step of the starter for the following motor: 10hp at 240V with an armature resistance of 0.5 ohm and full load current of 45 amperes. Starter current to be 15% of the full load current.



9.



$R_a = 0.5\ \Omega$

$I_{FL} = 45\ A$

$I_{ST} = 1.5(45) = \underline{67.5\ A}$

$R_T = \dfrac{240}{67.5} = 3.56\ A$

$R_1 = 3.56 - 0.5$

$= \underline{3.06\ \Omega}$

$E_{BACK\ 1} = 240 - 45(3.56)$

$= 79.8\ V$

$240 = 79.8 + 67.5(R_2 + 0.5)$

$R_2 = 1.87\ \Omega$

$E_{BACK\ 2} = 240 - 45(2.37)$

$= 133.35\ V$

$240 = 133.35 + 67.5(R_3 + 0.5)$

$R_3 = 1.08\ \Omega$

$E_{BACK\ 3} = 240 - 45(1.58)$

$= 168.9\ V$

$240 = 168.9 + 67.5(R_4 + 0.5)$

$R_4 = 0.55\ \Omega$

$E_{BACK\ 4} = 240 - 45(1.05)$

$= 192.75\ \Omega$

$240 = 192.75 + 67.5(R_5 + 0.5)$

$R_5 = 0.2\ \Omega$

$R_{STEP\ 1} = 3.56\ \Omega$

$R_{STEP\ 2} = 2.37\ \Omega$

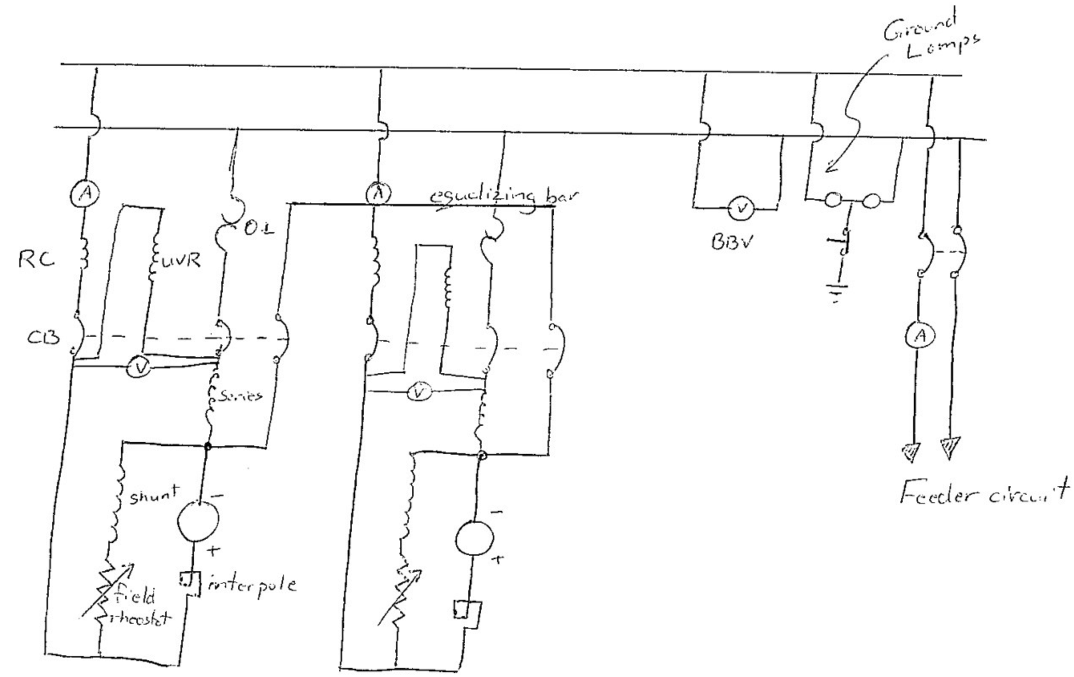
$R_{STEP\ 3} = 1.58\ \Omega$

$R_{STEP\ 4} = 1.05\ \Omega$

$R_{STEP\ 5} = 0.7\ \Omega$

84. Describe a diagrammatically sketch a main switchboard for a vessel having three D.C. current generators. Indicate on your sketch all the necessary fittings, meters etc. and explain the purpose of each.

1.



Switchboard for 2 DC Compound Generators

Instrumentation:

① Ammeters → for each generator and each feeder circuit
→ indicates current drawn by given machine or by a feeder or by total bus

② Voltmeters → one for each generator and one for the bus
→ indicates the voltage of a machine or bus

③ Ground detection lamps → indicates the presence of a ground fault on a distribution system.

④ Field rheostat → one for each generator
→ used to adjust voltage of generator + adjust load between parelled generators.

Protective Devices

1. Circuit breaker → to remove generator / load from distribution circuit
   → three pole for generator
   → two pole for each feeder circuit

2. Overload relay → provides over current protection
   → negative pole of each generator
   → designed to detect a certain magnitude of overcurrent and trip all poles of breaker if current exceeds the relay setting

3. Undervoltage protection → one on each generator
   → connected in parallel w/ main bus
   → if generator or bus drops below preset voltage value, the UVR will trip the CB
   → also prevents a dead generator from being connected to the bus

4. Reverse current relay → positive pole of each generator
   → prevents motoring of generator if loss of excitation or loss of prime mover
   → relay will trip CB if reverse current of 2 → 15% of full load current is sensed.

Paralleling DC Generators

1. Run incomming up to speed
2. Adjust voltage of incoming using field rheostat until slightly above bus
3. If compound wound, close equalizer bar manually.
4. Close breaker to incoming machine
5. Raise voltage using field rheostat on incoming and lower on others to share load.
6. Repeat for other generators.

85. Assuming one generator is on load, describe the procedure necessary to bring the other two machines on to the busbar so that the three generators may run in parallel.

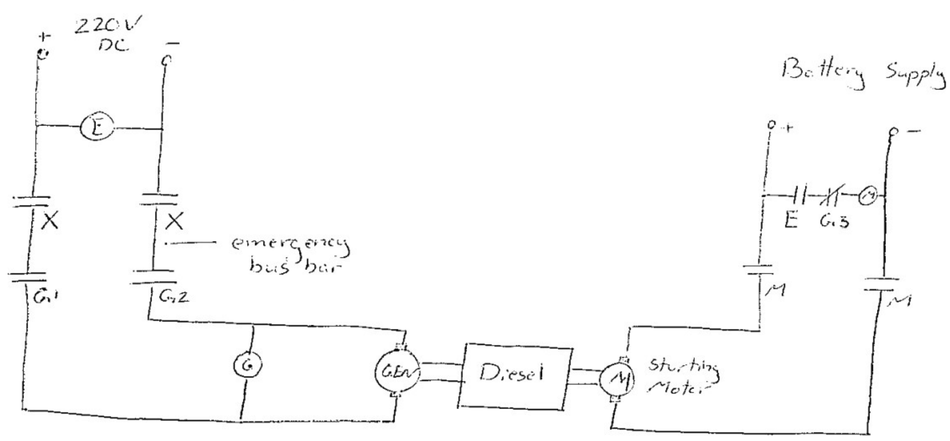
86. Enumerate the advantage and disadvantages of a D.C. Electrical Installation (for lighting and auxiliary purposes) as compared with a similar A.C. system.

2. Comparison of AC + DC Distribution systems

Consideration	DC	AC
① Supply different values of voltage to aux. equipment.	Requires use of static conversion equipment or rotary converter (MG set)	Very simple through use of transformers.
② Line losses	Constant for given load	Varies with pf. Must maintain high pf.
③ Size of rotary equipment	Much larger for same voltage and power rating	Smaller and more efficient.
④ Maintenance of rotary equipment	Commutators, brushes, + slip rings	No commutators, brushes, or slip rings
⑤ Magnitude of supplied voltage	Limited since voltage is taken from a rotating commutator.	Higher voltages possible. Stators are easily insulated.
⑥ Distribution	Line losses higher since transformation is not an option.	Distribute at high voltage to lower current + therefore reduce losses.
⑦ Frequency	Not applicable	Higher frequency permits reduction in size of machinery

87. Discuss the starting sequence of an emergency generator which starts, automatically, in the event of a main power failure.

9. Emergency Generator



- when power fails on main bus, relay E will de-energize and contact E will close
- motor starting circuit completed when M holding coil is energized and M contacts close.
- diesel is now started
- once diesel starts, G relay is energized and G3 will open to disconnect the starting motor
- at running speed, G relay is strong enough to close G1 & G2 and supply the emergency bus with power
- X contacts are closed by bus tie breaker to the main bus

Circuits Fed

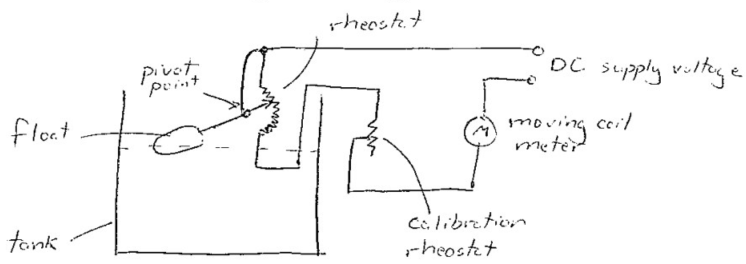
gyro searchlight
navigation lights
alarm system
whistle
passageway lights
radio equipment
steering gear
fire p/p
CO_2 fire system

Precautionary Devices

Fuses
Circuit breakers
Overload relays
Reverse current relays

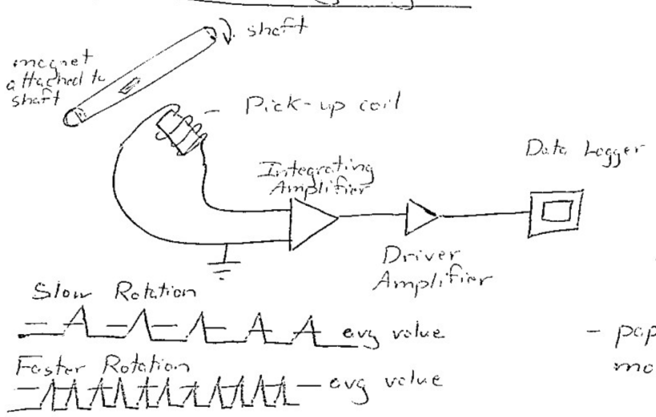
88. Detail a method of converting the measurement of the level of a liquid in a tank and the revolutions per minute of a shaft into an electrical signal for input into a data logger.

3. Liquid Level Indicating System



- based on principle that DC current flow through moving coil meter will cause it to deflect in proportion to magnitude of current flowing in closed circuit.
- height of fluid in tank will determine position of float
- float controls position of tap on rheostat
- amount of resistance left in series circuit will determine new meter deflection
- if float rises, tap moves down and decreases resistance
- higher current flow will indicate higher level
- second rheostat used to calibrate system.

RPM Indicating System



- as shaft rotates, permanent magnet induces a pulse of voltage as it passes the pick-up coil
- integrated value of voltage is amplified to operate the data logger.
- a stylus operated by the driver amplifyer will record the rpm.
- paper moves right to left by internal motor

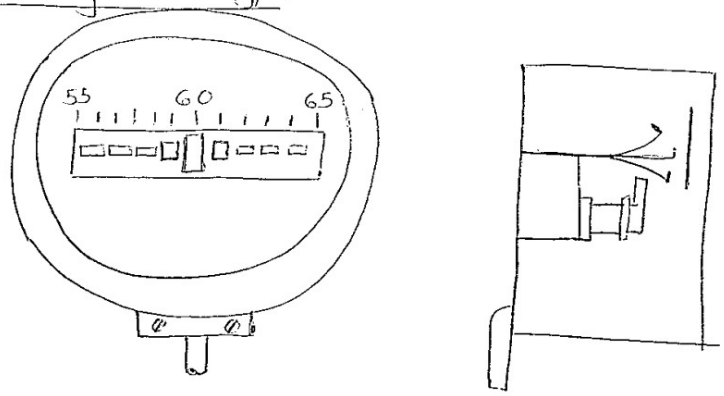
- with faster rotation, pulses are closer together
  - higher average value is recorded by data logger

89. Using a sketch to illustrate an amplify your answer, describe anyone of the types of frequency meters listed below:

i. Vibrating reed type
ii. Moving disc type for frequency meter
iii. Electrodynamics type

1. Frequency Meters

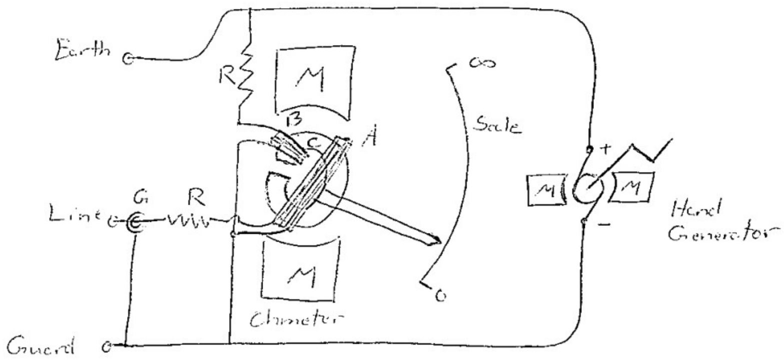
a) Vibrating Reed Type



- based on principle of mechanical resonance
- series of reeds fastened to flexible common base mounted on the armature of an electromagnet
- coil of magnet energized by a.c powerline of frequency to be determined.
- reeds tuned to natural frequency by selection of mass and length
- reed with same natural frequency as source builds up vibration
- vibrating reed visible through window in front of meter
- if frequency is intermediate, 2 reeds will vibrate and frequency is determined by reed with largest vibration.
- simply constructed and rugged
- maintains calibration well if reeds aren't excessively vibrated.

90. Describe the "megger". How is it used in testing circuits and equipment?

4. Megger Insulation Tester



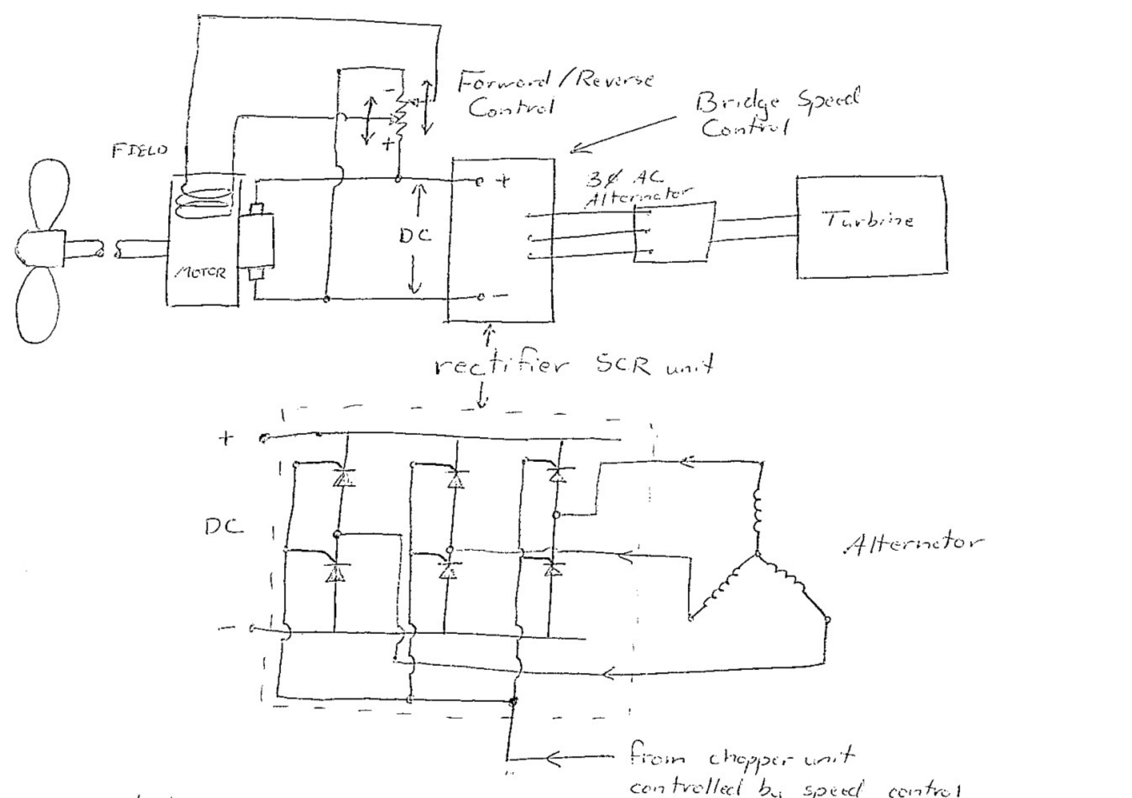
- if nothing is connected across the earth and line terminals, the current will flow through R and coil B back to the negative terminal of the generator, when the generator is cranked.
- the magnetic field set up around coil B will interact with the field of the magnets (M) and cause movement of the coil assemblies A and B.
- the pointer, attached to coil A, will move toward ∞.

- with a resistance across earth & line, current will have a path from generator, through external resistance and coil A, back to the generator
- coils A and B both have current flow and field of A opposes that of B.
- if enough current flow through A, it will cancel effect of B and cause the pointer to move toward 0 on the scale.
  - indicate relative size of the external resistance on the terminals

- used to ensure the windings of the armature and field are not shorted to one another or grounded to the case of the machine.
- megger is essentially an ohmmeter that receives its voltage from a generator
- has much higher voltage than conventional ohmmeters and can simulate actual conditions when testing is done

91. Describe an electric propulsion system employing a turbine driven alternator and direct current propulsion motor. Use a sketch to help illustrate your answer. Why is the propulsion system made more complicated by employing A.C. and D.C. rather than the use of only one or other of these power modes. What type of rectification arrangements would likely be used in such a system? There is a physical limit to a maximum power available as output for which a direct current motor can be built. How does the designer overcome this restriction if much greater power per shaft is desired?

Section 24



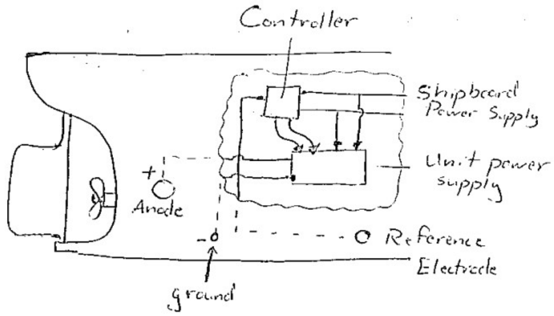
- turbine drives 3 phase alternator which provides 3 phase 440V to SCR rectifier unit which converts supply to DC.
- level of DC supplied to motor brushes dependent upon speed controller which in turn controls the chopper unit
- chopper unit determines how much of each half cycle of 3 phase A.C. is effective. This will control prop. speed.
- reversal obtained by reversing polarity of motor shunt field through use of potentiometer
- controlled from bridge
- will also regulate torque

92. Describe a typical impressed cathodic protection system used in a ship. What are the values of current and voltage used? What problem may be encountered if a current appreciably higher than recommended by the equipment supplier is applied?

2. Hull Corrosion

- result of electrochemical action
- when metals immersed in conductive liquid, electric potentials developed & current flows, creating corrosion.
- electric potentials result of galvanic series

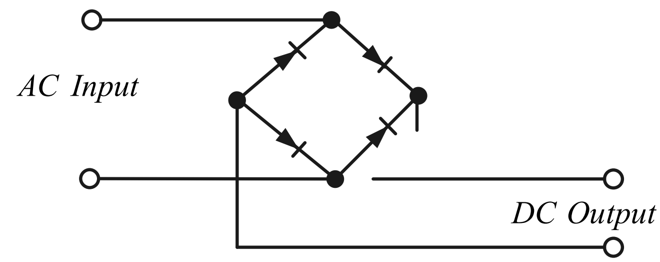
Impressed Current System



- hull → cathode
- fitted element → anode
- negative emf applied to cathode and positive to anode
- ions leave fitted element and mixed with hydrogen ions in seawater.
- hydrogen ions form polarizing film on cathode (hull) and insulate it, reducing current transfer from the anode.
- as ship moves through water, fresh oxygen dissolved in water destroys the film and emf must be increased.
- anode is platinized titanium (highly corrosion resistant)
- reference electrode is fitted to hull and measures potential difference between hull surface and electrode.
- adequately protected → 0.80 to 0.85 V difference
- current should be between 20 to 100 mA / m^2
- too much current will strip paint from the hull and expose the steel

→ current applied depends on rate of supply of dissolved oxygen at cathode surface. These factors are:
1) amount of bare steel
2) speed of ship through water
3) water temp (warmer water has faster current flow)

93. Describe the construction of a semi-conductor rectifier indicating the materials used. Sketch the output wave of the bridge rectifier illustrated. If a capacitor was connected across the output terminals, what effect will it have on the waveform?



4. Semiconductors

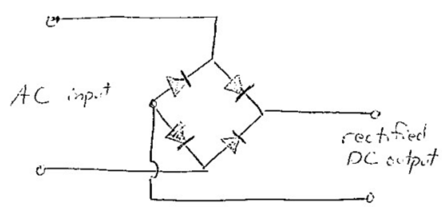
N - type → pentavalent

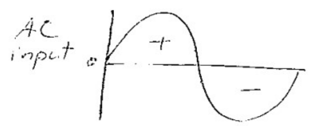
- pentavalent atom such as arsenic is introduced into germanium crystal lattice, one of the electrons of the impurity atom is free to become a -ve charge carrier.

P - type → trivalent

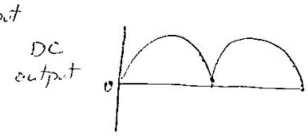
- trivalent atom such as aluminum is introduced into germanium crystal lattice, and is one electron short → hole

- The holes in the P side collect electrons from the N side leaving more holes on the N side. The holes will appear to move in the opposite direction of the electron



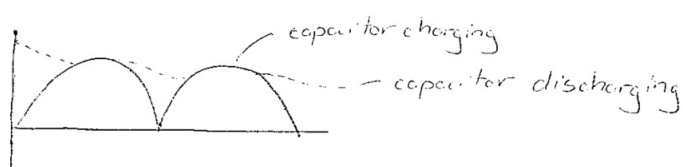


input to bridge rectifier



pulsating DC
A positive pulse for every half cycle of input AC.

- with capacitor across output terminals



- capacitors serve to smooth rectified DC output and give higher average value.

94. Discuss the precautions required when electrical equipment is to be used in flammable atmospheres.

What is meant by the following terms?

i. Intrinsically safe circuits

ii. Flame-proof apparatus

8. Precautions of Electrical Equipment in Flammable Areas

a)

- no electrical equipment or wiring allowed in cargo oil tanks or cofferdams, or pump rooms
- wiring or electrical equipment installed in adjacent space is to be flame proof
- ungrounded cables must be protected by metal guards or traps from phsical damage
- Flame proof lighting may be fitted in pump rooms
- light fittings must have glasses secured with screws or nuts requiring special Key for removal
- lighting circuits must be connected to 2 independant sources so one can be isolated for repairs/maintenance.
- any temporary equipment to be located in spaces must be classified as "flame proof".

b) Instrinsically Safe

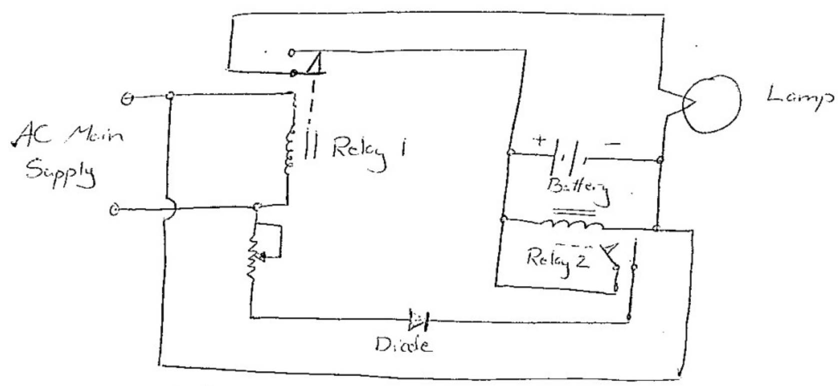
- a circuit in which any electrical sparking that may occur in normal and fault conditions specified by certifying authority, and with the prescribed components, is incapable of causing an ignition of flammable gas or vapour.

Flameproof or Explosion Proof

- an enclosure that is capable of withstanding without damage, an explosion of a gas or vapour that may occur within it, and be capable of preventing the ignition of gas or vapour surrounding the enclosure from sparks, flashes, or explosion of the specified gas or vapour within the enslosure.

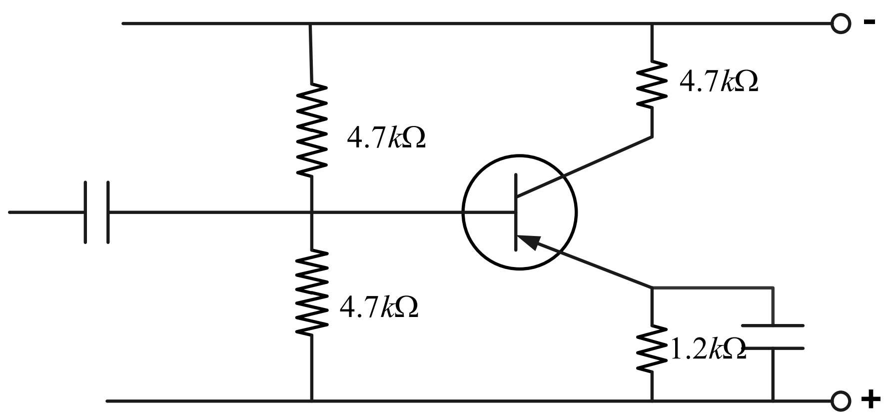
95. Describe an emergency lighting system which uses batteries. What care and maintenance does this system require?
How are the batteries changes when the available power is A.C.?
Make a line diagram of such a circuit.

4. Emergency Lighting

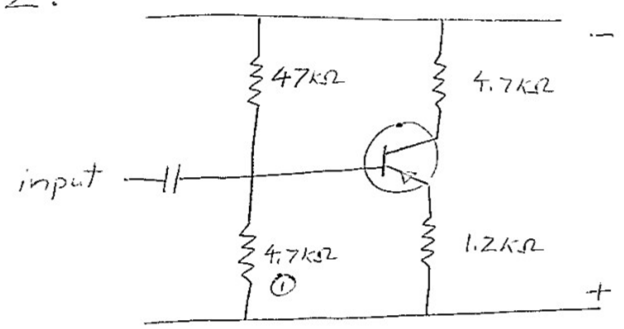


- when battery voltage falls below certain value, circuit will automatically connect a charging circuit to restore battery's voltage.
- when normal ac mains voltage is present, relay 1 is energized and holds its contacts open, disconnecting the battery from the lamp.
- when normal ac fails, relay 1 de-energizes and allows contacts to close, completing the supply to the lamp.
- relay 2 designed with many turns and high resistance so it doesn't take much from the battery
- if battery voltage falls below normal, relay 2 will de-energize and charging circuit from the mains will be complete.
- diode used to form half-wave rectifier for charging circuit
- rheostat initially set for charging current
- maintenance
  - test batteries and lamp, functioning of circuit
  - replace batteries if no-charging circuit is used

96. The circuit illustrated is that of a typical common-emitter amplifier. If the current through the emitter resistor is 0.5mA, determine the battery voltage. Assume a base emitter voltage drop of 0.1 volt.



2.



$I_e = 0.5\,mA$

$V_{BE} = 0.1\,V$

$$V_{1.2} = (1.2\cdot10^3)(0.5\cdot10^{-3}) = 0.6\,V$$

Consider circuit as 2 voltage dividers in parallel

1) 47 kΩ across supply
2) 4.7kΩ Collector to Emitter
3) 1.2kΩ across supply

$$V_{4.7①} = V_{1.2} + 0.1V = \underline{\underline{0.7\,V}}$$

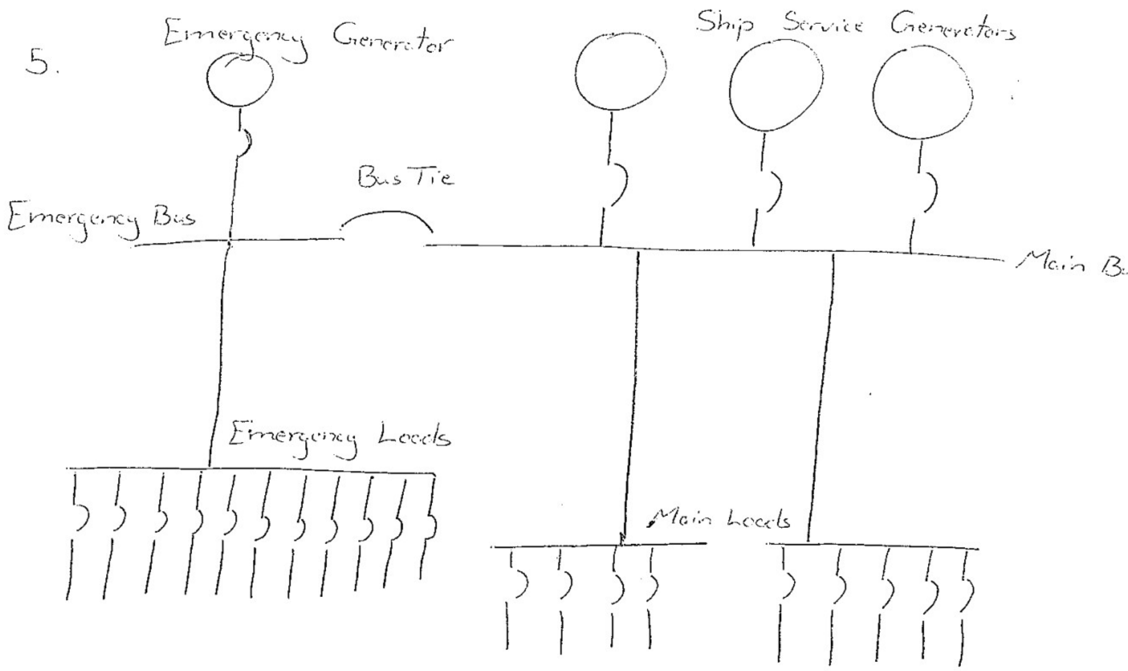
$$I_{4.7} = \frac{0.7}{4.7\cdot10^3} = \underline{0.149\,mA} = I_{47}$$

$$V_{47} = (0.149\cdot10^{-3})(47\cdot10^3) = \underline{\underline{7.0\,V}}$$

$$V_{supply} = \underline{\underline{7.7\,V}}$$

97. Describe any emergency power installation fitted aboard ship. State the circuits this generator feeds and list the various connections on the switchboard of this installation.

5.



- normal operation – ship service generator feeding main and emergency bus, bus tie breaker closed
- emergency operation – emergency generator feeding emergency bus and all emergency loads, bus tie breaker open
- to return to normal – ship service generator on main bus synchronized with emergency bus through bus tie and emergency generator taken off load.

<u>circuits fed for emergency</u>

Navigation lights
Radio equipment
Emergency lighting
Gyro compass
Steering Gear
CO_2 Fire System for E/R
Searchlight
Fire p/p

<u>precautionary devices</u>

Reverse current devices
Fuses
Circuit breakers
Overload relays