EEE 451

⁝ Some Regulations IEE

Wiring & Safety regulations

Generation, Transmission & Distribution.

⁝ Consumer Circuits.

Arrangement of final sub-circuits.

Radial circuits, ring circuits for socket outlets

Circuit arrangements for lighting & switching

One way & two way switches.

⁝ CONDUCTORS & CABLES – Makes, types, sizes, rating & temperature coefficients & fuses

⁝ Design Considerations

starting point: Architectural & Structural drawings.

Determination of use of premises.

Selection of luminous level.

Selection of luminaires and calculation

IS 60:1-3
Eph 6:14-17
Mt 5:12
1Th 5:8
Mt 8:11

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Cost consideration, availability, alternatives & regulation

Selection of fittings and cable sizes for the various circuits.

Load analysis, protection & control.

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EARTHING , TESTING & INSPECTION.

……

Feasibility studies :

cost vs return on investment
distance of load center from source or nearest substation

Reason for selection of transformer rating
cost, capacity, flexibility, growth anticipated load, convinience, uniformity availability etc

Distribution

Sag, Span, Poles

Compensation . Reactive power vars generated by line effect on system extra capacity. etc.

Transmission

Construction cost pick up cost & rate maintenance cost etc

Production & Generation.

Regulations.

Owing to the peculiar properties of electricity, regulations have been made to ensure satisfactory results from the installation, to protect the building and its contents from the risk of fire, and to safeguard users of electricity from shock.

I.E.E. Regulations for Control, Distribution and Excess-Current Protection

Section A, include the following:

Every consumer's Installation supplied from an external source shall be adequately controlled by switchgear accessible to the consumer, the switchgear to incorporate:

1. means of isolation
2. Means of excess-current protection and
3. Means of earth-leakage protection, though

this may not be needed where the impedance of the earth-leakage path is so low that the excess-current protection also gives earth-leakage protection

The general sequence of main switchgear etc, shall be service fuses and neutral link, if any; Watt-hour meter and time switch, if any; linked switch and consumer's main fuses, or excess-current circuit-breaker with or without earth-leakage trip; and consumer's distribution board. The ~~Consumer Unit~~ Consumer's Main fuses may be omitted under certain conditions see reg A3
The sequence of control given above is clearly shown in each of the Fig 7 to 12

Consumer's Control Unit. In a small installation the consumer's linked switch, main fuse, and distribution board as separate items can be combined in one case as a consumer's control unit. This makes for neatness, cheapness, and ease of installation

Single - pole fusing

Regulation A8 states that in a 2 wire installation connected to earth on one pole, all fuses, and single - pole control devices, e.g. switches, circuit - breakers and the like, shall be connected in the live conductor only. A 2-wire non-earthed installation will require double - pole linked devices in both conductors. {for better contact. Since the installation is not earthed}.

Relative rating of conductors and protective devices, Regulation A 10
Every conductor in an installation shall be protected by a fuse or

Circuit breaker fitted at the origin of the circuit of which the conductor forms a part. The current rating of every fuse used for this purpose shall not exceed the current rating of the lowest rated conductor in the protected circuit, while every circuit-breaker shall operate when subjected to a sustained current 1.5 times the rated current of the lowest rated conductor

There are a number of exemptions to this Regulation, and these should be studied.

In this Regulation account is to be taken of the class of excess-current protection afforded by the fuse or circuit-breaker, close or coarse.

The IEE definition of close & coarse excess-current protection is given below

Close : Will operate Within four hours at 1.5 times the designed load Current of the circuit which it protects. Certain types of fuse, and Miniature and other circuit-breakers will afford this protection.

Coarse; will not operate within 4 hrs at 1.5 times the designed load current of the circuit which it protects. Certain other types of fuse give this protection.

Diversity Regulations A21 and A22 allow the application of a diversity allowance to the size of circuit Conductors, other than those of a final Sub-circuit, where conditions justify. This allows For a Connected Load whose aggregate Current is greater than the current rating of the Conductors Supplying the load

Regulations A27 & A28 allow some diversity to a final sub-circuit supplying cooking appliances.

Final sub-circuits, Regulations A23 and A26 Where an installation comprises more than one final sub-circuit, each shall be connected to a separate way in a distribution board. The wiring of each sub-circuit shall be separate from that of any other.

The number of points supplied by a final sub-circuit ~~is limited~~ of rating not exceeding 15 A is limited by their aggregate demand as given by I.E.E Table A2. NO diversity is allowable except as shown in the Table

A final sub-circuit with rating exceeding 15 A shall not supply more than one point except for exemptions in regard to cooking appliances and 'ring' and 'radial' circuits

Domestic ring & radial circuits general Regulations A 30 to A 33. In domestic installations, either radial or ring circuits confirming with Table A.3M of the Regulations may be installed to serve 13 A flat pin socket-outlets (B.S.S 1363) and stationary appliances of rating not greater than 13 A, given that

Each socket-outlet of a twin or Multiple unit is reckoned as one socket-outlet. A permanently connected stationary appliance shall be locally protected by a fuse not exceeding 13A and controlled by a switch or circuit-breaker to disconnect all live conductors. The switch should be separate from the except for exemptions in regard to cooking appliances and 'ring' and 'radial' circuits

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Table A.3 M of the Regulations gives corresponding numbers of 13 A socket-outlets, minimum cable sizes and fuse or circuit-breaker rating for domestic radial and ring circuits
Where circuits are installed in groups or in conditions of high ~~ambil~~ ambient temperature, the cable sizes given shall be increased as necessary

Domestic ring circuit: Each circuit conductor of a ring final sub-circuit shall be run in the form of a ring, looping in to socket-outlets and joint boxes, starting at and returning to the same way in a distribution board. If the conductors are cut instead of looped at the socket-outlets and joint boxes, they must be so jointed as to have electrical continuity.

Unless the circuit is run throughout in metallic conduits, ducts or trunking, an earth-continuity conductor shall also be run as a ring and be earthed at the distribution board.

The number of spurs must not exceed the total number of socket-outlets and stationary apparatus connected directly in the ring

Fused spurs must be connected through fused spur boxes in which the rating of the fuse must not exceed the rating of the cable forming the spur, nor be greater than 13 A

Non-fused spurs must be connected at the terminals of socket-outlets or at joint boxes. Not more than two socket-outlets or one stationary appliance are to be fed from each non-fused Spur.

In a house or flat, with one ring circuit for each ~~100²~~ 100m² of floor area, an unlimited number of 13-A socket outlet with fused plugs may be connected to one ring circuit which is fused at 30A, and whose conductors are of size 2.5mm² (1/1.78

Non-domestic radial and ring circuits, using 13-A socket-outlet, Regulation A42. These types of circuit may be installed conforming to the foregoing regulations for domestic radial and ring circuits, provided the maximum demand does not exceed the current rating in I.E.E Table A.3 m.

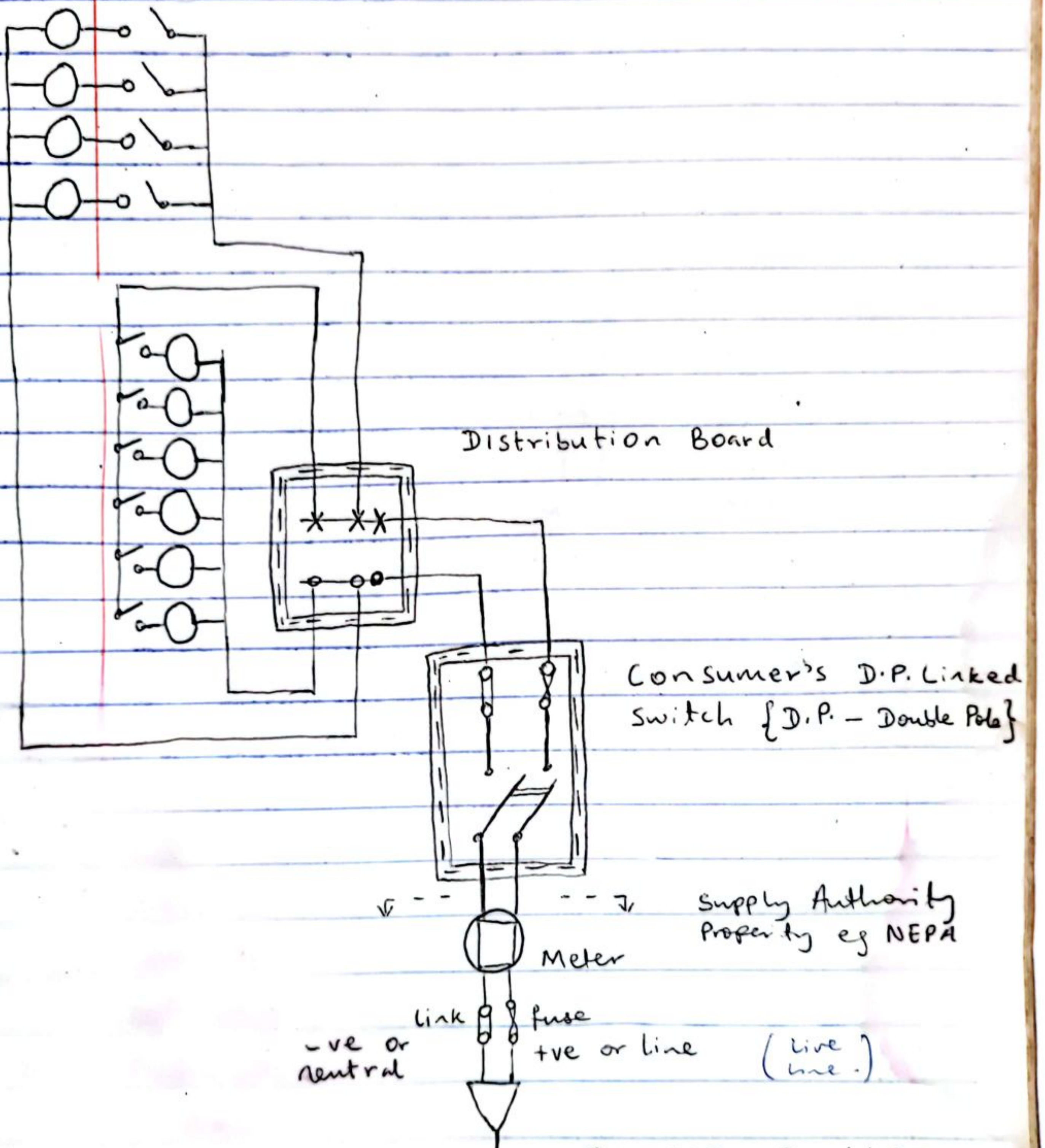
~~Ato~~

Non-domestic radial and ring circuits, using B.S. 196 socket-outlets (round-pin with rating 5A, 15A, & 30A) Regulations A43 to 55

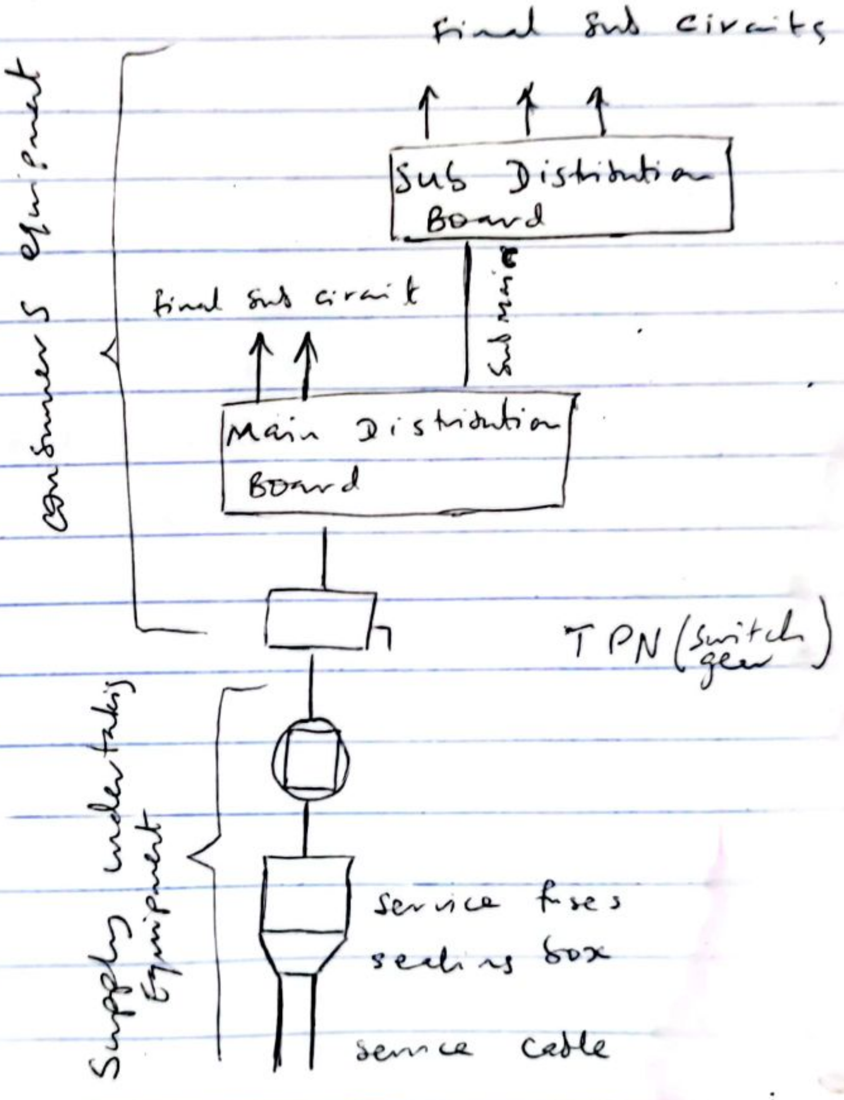
The Regulations covering the installation of these circuits are broadly similar to those covering domestic radial and ring circuits. They vary in detail and should be carefully studied.

Portable appliances, Regulations A56 and 57. Every portable appliance and portable lighting fitting shall be fed from an adjacent accessible socket-outlet. socket-Outlets used on direct current require to be controlled by a switch either combined with the socket-outlet or immediately adjacent. NO Switch is needed with alternating current provided the plug can be readily with drawn

Control of appliances and lighting fittings not supplied from socket-outlets, Regulations A58 to 60. An appliance or lighting fitting not supplied from a a socket-outlet must be controlled by a switch or switches so as to disconnect all bif live conductors. Where a heater element can be touched or where more than one phase is introduced into the appliance, a linked switch is required to disconnect all circuit conductors. The switches are normally to be separate from the apparatus and readily accessible, but may be mounted on the appliance under certain conditions.



SIMPLE 2-WIRE INSTALLATION



Sequence of Supply Control

Cables & conductors

Forms of insulation

General Purpose rubber compound
butyl rubber
silicone rubber
Polyvynil Chloride (PVC
polythene
impregnated Paper
bitumen
Magnesium oxide (MICS)
Varnished cambric
treated paper
and braid. (P.B.J)
asbestos
glass fibre

Mechanical Protection
lapping: of proofed tape and or
waxed cotton braid
Sheath of rubber compound
Synthetic rubber
Polyvinyl chloride

Polythene, lead alloy, Copper
aluminium
In some instances it may include
armouring of steel wire or tape
or enclosing cables in metallic or
non metallic conduit
troughing or casing

Bare

P41 TG FRANCIS Regulations A34 to A41

In a house or flat, with one ring cct for each 100 m^2 of floor area, an unlimited number of 13 A socket outlets with fused plugs may be connected to one ring cct which is fused at 30A, and whose conductors are of size 2.5 mm^2

$$\text{Diversity factor} = \frac{\text{maximum load at one time}}{\text{Sum of total loads}} \times 100$$

cooker 30A

The current rating of stationary cooking appliances as stated above is obtained by taking the first 10A of the total load and adding to this 30% of the remainder. An additional 5A would be required for a socket outlet incorporated in the cooker control Unit.

The diversity factor for the lighting of residential blocks of flats is 50%. So that if the total lighting load of a block of flats is 60A, then the Switchgear and mains need only be rated at 30A

For industrial situations, the percentage

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For industrial situations, the percentage diversity factor would be high, as frequently the whole of the lighting and machines are put on together.

Care has to be taken when applying diversity it requires sound knowledge of the particular installation.

Except for domestic cookers and circuits involving 13A socket outlets, no diversity is permitted for final sub circuits.

Eg. An installation to a private house connected to a 240V ac supply and contains the following conds

(i) 1500W lighting (ii) Two 30A ring circuits
(iii) 60A cooker, with the control unit incorporating a 13A socket outlet.

Determine the current which must be assumed to decide the size of the main cables and switch gear, assuming the following diversity factor allowances

Lighting - 66 %

Ring circuit - 100% fuse rating first ring + 50% remainder

Cooker - 30% full load in excess of 10A + 5 A for socket outlet

b) Compare the assumed current with the maximum load

c) Determine the percentage reduction in maximum load by use of the diversity factors.

Applying Diversity factors

a) (i) Lighting current $= \frac{66}{100} \times \frac{1500}{240}$

$= \frac{1500 \times 2}{240 \times 3} = 4.166A$

(ii) Ring circuit $= 30 + 15 = 45.00A$

(iii) Cooker current $= 10 + \frac{30 \times 50}{100} + 5 = 30.00A$

Total assumed current = 79.17 A

b) Maximum load $= \frac{1500}{240} + (2 \times 30) + 60 + 13 = 139.25$

c) Percentage reduction $= \frac{(139.25 - 79.17)}{139.25} \times 100$

$= 43\%$

Rating

Unless specially designed to break inductive circuits, the rating of switches controlling fluorescent fittings must be reduced by 50% that is they must have a rating of twice the current it is required to control.

Eg A single-phase supply consist of sixty 80W fluorescent fittings and thirty 100W filament lamps. Assuming no diversity calculate the size of main control switch required. The supply voltage is 240V

Current allowance for flourescent tube

$$= 2P/V$$

$$= \frac{2 \times 60 \times 80}{240}$$

$$= 40 A$$

Current allowance for filament lamps

$$= P/V$$

check → $= \frac{*300 \times 100}{240}$?

Should be $\frac{30 \times 100}{240}$

$= 12.5 A$ $= 125 A$ $\{40 + 12.5 = 52.5A\}$

Total current $= 40 + 125 = 165 A$ nearest size $= 60A$

Nearest main switch size is 200 A

Assuming the control gear power factor is not less than ·85 lag. then the demand for flourescent fitting in volt-amperes is taken as 1.8 times the rated lamp watts Thus 80 W lamp would be rated at 880×1·8 that is 144 W

All control gear must be situated as near to its associated lamp as possible.

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Situation requiring lighting	Recommended illuminance (lux)
home casual reading	150
teaching spaces	300
woodworkshop (rough sawing, benchwork)	300
Machine and fitting shop (fine bench & machine work)	1000
sheet metal work	500 - 750
self service shop	500
stairs and building area	150
underground car park	30

$$\text{lighting flux} = \frac{\text{illuminance} \times \text{area}}{\text{utilisation factor} \times \text{Maintenance factor}} \quad (\text{lumens})$$

$$\phi = \frac{EA}{UF \times MF}$$

Cables

Varnished Cambric Insulated Cables

rolls of varnished cambric sheet are cut into narrow strips and applied to the conductor in a similar way to that used for impregnated paper insulation. Usually consecutive layers of cambric are separated by a serving of petrolleum jelly. The cable may be taped, braided and compounded or lead-sheated

Varnished cambric insulated cable, when not sheathed may be used only where short lengths are required and where it will not be exposed to moisture. It is frequently used for switchboard connections and in power stations.

Polychloroprene Insulated Caples (P.C.P)

Trade name. 'Neoprene' has good mechanical properties, resistant to oils, (sometimes used for cable insulation instead of rubber)

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Trade name 'Neoprene' has good mechanical properties, resistant to oils, (Sometimes used for cable insulation instead of rubber)

Petrol and solvents and is non-flammable but its electrical characteristics are inferior to that of natural rubber. P.C.P sheathed cables are used where there is exposure to steam, ammonia and sulphur fumes or lactic acid.

* Rubber or Plastic Sheathed Cables

{ Cable terminations should be contained in incombustible enclosure, the sheath being cut back a short distance from the end of the insulation.

*

Armoured Cables

Cables insulated with Vulcanised rubber, plastics, or impregnated paper are sometimes armoured for underground use or where considerable mechanical strength is required. The armouring consists of galvanised iron or steel wire or steel tape, in single, double or even multiple layer, according to requirements.

Wire armouring is generally used on smaller sized cables and also where the armouring has to carry weight with considerable
flexibility as in cables suspended vertically in shafts. Metal tape affords better mechanical protection than wire

The armouring may be used in combination with braiding over plastics or over a metal sheath. Impregnated tape between a lead sheath and the steel reduce risk of the armouring cutting or deforming the lead and prevents electrolytic action b/w the two ~~cables~~ metals. Impregnated hemp or jute may be used to protect the armouring.

* Protection, generally by means of conduit or capping is necessary anywhere there is risk of mechanical damage. When cables pass through structural metalwork, the hole must be bushed to prevent abrasion. Non-metal-sheathed cables must not be exposed to direct sunlight unless provided with a sheath of PVC or oil-resisting and flame-retardant material or H.O.F.R,

* preferably black in colour.

{H.O.F.R compound}

Heat, oil, fire resistant cable

Regulation B 16 Where ~~exposured~~ exposed to oil or petrol, flexible cords or cables shall be sheathed with P.C.P, P.V.C or ~~ho~~ h.o.f.r.

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Mechanical Protection for large Cables

Unarmoured Cables:

These could be run without further protection than the lead sheathing. A further protection is one or two layers of compounded jute or hessian tape yarn laid over the lead sheath. Aluminium is used as an alternative to lead for sheathing cables.

Armoured Cables:

This includes single-wire armouring (a single layer of galvanized iron wire laid spirally upon a bedding of jute or hessian), double-wire armouring (ie two layers of armouring), and double steel tape armouring (two layers of steel tape laid spirally over the bedding with an overall finish of jute and hessian).

Aluminium strip armouring is

Sometimes used as an alternative to wire armouring

For underground cables, wire armouring is used where the ground is liable to subsidence, to prevent the cable from breaking, whereas steel tape armouring is needed where physical damage from stones or workmen's tools may be expecte

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Silicone rubber:

Cables insulated with silicone rubber material may be used where the conductor temperature does not exceed 145°C

Silicone-rubber, butyl-rubber and ethylene-rubber-insulated cables are made up according to requirements as textile-braided and compounded, glass braided and compounded, or with various qualities of heat-resisting, oil-resisting, and flame-retardant sheathing (h.o.f.r)
All the elastomer-insulated cables are made in the 600/1000V range.

Elastomers: generic term for

Vulcanized rubber	(V.i.r)
butyl rubber	(b r)
ethylene-propylene	(e.p)
silicone rubber	(s.r)

Paper-Insulated lead-sheathed Cables

These are circular cables having one or more copper conductors insulated with layers of impregnated paper tape and covered with a lead or lead-alloy sheath. The current-carrying capacity of this type of cable is greater than that of equivalent vulcanised rubber insulated cable. It is used a great deal for heavy current work.

Precausion must be taken to ensure that the ends of cable are effectively sealed at terminations and that joints are moisture proof.

Bending of paper insulated cables must be done carefully and the radius of the bend should always be as large as possible never less than twelve times the overall diameter of the cable.

The cables may be installed indoors or outdoors, laid directly in the ground or drawn into ducts. For long runs, direct burial in the ground, ~~or drawn into ducts. For~~ with protection by boards or tiles in soft ground, is commonly employed as it is cheaper than drawing into ducts and permit a higher current carrying capacity.

This method is not usually applicable in the congested areas in cities and towns; in these situations it is usual to install earthenware ducts with manholes at suitable intervals and to pull in the cables afterwards. This has the advantage that cables may be easily replaced and, provided the wiring capacity of the duct is adequate, fresh cables may be added if required.

Voltge range from 600/1000V to 19000/33000V mainly for underground laying.

The insulation after being vacuum-dried is impregnated under pressure with mineral oil or other suitable compound.

Owing to the affinity of paper for moisture the insulation is completely enclosed in a continuous lead or aluminium sheath extruded over the insulation. All cable ends are sealed by special oil-filled or compound-filled. sealing boxes.

Mineral insulation:

copper or aluminium conductors with compressed powdered mineral insulation enclosed in a copper or aluminium sheath M.i.m.s may be used according to the termination used, up to an ambient temperat of 150°C & a much higher cable temperature. Specially designed arrangements are needed at all joints and terminations. These cables are made in the 600-V class (light duty) and the 1000 V class (heavy duty)

N.B:

Flexible wires varying in size from 0.5mm² (16/0.20) to 4mm² (56/0.30) are called flexible cords. Flexible wires of larger sizes from 6mm² (84/0.30) to 630mm² (2257/0.60) are called flexible cables. (Number & diameter of wires in mm²) {NO./dia. mm}

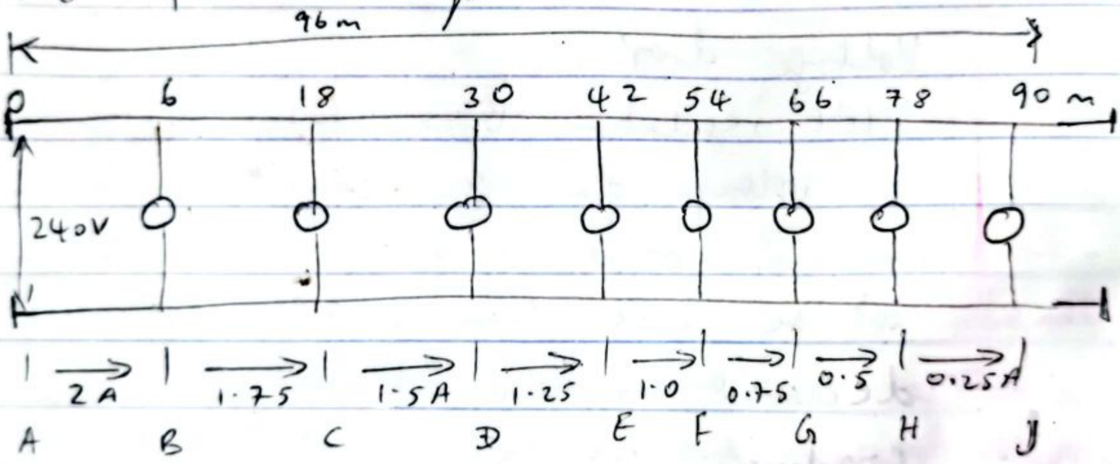
Voltage drop.

IEE regulation B23 states that the drop in voltage from the consumer's terminals to any point in the installation shall not be more than 2.5% of the declared or nominal voltage when the conductors are carrying the full load current, disregarding starting conductors.

For a 230V supply the allowable voltage drop is $\frac{2.5}{100} \times 230 = 5.75\,V$

for a 240V supply. the voltage drop is 6.0V.

A corridor 96 ~~meter~~ metres long is to be lighted by 240-V, 60W lamps spaced 12 metres apart, and controlled by one switch at the supply end. The wiring is to be single-core P.V.C.-insulated cables enclosed in metal conduit. Find the size of wire required



distance b/w the lamps is twice distance from the wall to the lamp

Current per lamp $= \frac{60}{240} = 0.25A$.

Max current is 2A ie section AB

Notice that the lamps are connected in parallel. each branch will have a current of 0.25A passing through it. the line feeding any branch would have the sum of all the ~~agregat~~ currents flowing through the remaining branches progressively till the last branch where the line feeding the branch & the parallel branch will both have a current of 0.25A passing through them.

The allowable volt drop is 2.5% x 240
= 6V

Voltage drops for cable sizes per A, per unit length (metre) are usually given in tables.

a cable 1.0 mm² (1/1.13) has a volt drop per amp ere per metre run of 40 mV, and a current rating of 11 A. Thus when the cable carries 2 A, the volt

1.0 mm² cross sectional area of conductor

(1/1.13) Number of conductors / diameter of each conductor

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1.0 mm² cross sectional area of conductor

(1/1.13) Number of conductors / diameter of each conductor drop in AB will be, 40(mV) × 2(A) × 6(m)

Voltage drop in				Volts
AB	=	40 × 2 × 6	= 480 mV	= 0.48
BC	=	40 × 1.75 × 12	= 840 mV	= 0.84
CD	=	40 × 1.5 × 12	= 720 mV	= 0.72
DE	=	40 × 1.25 × 12	= 600 mV	= 0.6
EF	=	40 × 1.0 × 12	= 48 mV	= 0.48
FG	=	40 × 0.75 × 12	= 360 mV	= 0.36
GH	=	40 × 0.5 × 12	= 240 mV	= 0.24
HJ	=	40 × 0.25 × 12	= 120 mV	= 0.12
			Total volt drop	= 3.84

This value of volt drop is less than the allowance of 6V, thus the cable chosen is of suitable size.

However if the total volt drop is more than the allowable volt drop then we choose the next bigger size of cable and go over

Type of circuit	Overcurrent protective device		Minimum conductor size	
	Rating	Type	Copper conductor rubber or PVC insulated cables	Copper conductor rubber or PVC insulated cables
1	2 A	3	4	5
A1 Ring	30 or 32	Any	mm² 2.5	4 2.5
A2 radial	30 or 32	Cartridge fuse or circuit breaker	4	4
A3 Radial	20	any	2.5	2.5

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A1 Ring	A 30 or 32	Any	mm^2 2.5	4 2.5
A2 Radial	30 or 32	Cartridge fuse or circuit breaker	4	4
A3 Radial	20	any	2.5	2.5

Copper conductor mineral-insulated cables	Copper clad aluminium conductor P.V.C insulated cables	Maximum floor area served
~~3~~ 6	5	7
1.5	4	100
	6	50
2.5		
1.5	4	20

Draw a circuit diagram of each of the following

a) ~~Six~~ two lamps controlled by a one way switch. Draw two diagrams. One indicating how the circuit would be connected in practice and the other indicating the principle of operation.

b) Four lamps controlled by two two way switches. Draw two diagrams. One indicating how the circuit would be connected in practice and the other indicating the principle of operation.

c) A radial circuit of a socket outlet meant for the following appliances; indicating the rating of the fuse or circuit breaker you will recommend.

(i) radio

(ii) AC

d) A ring circuit for 5 socket outlets; indicating the rating of the socket outlets and the rating of the fuse or circuit breaker recommended for the circuit.

Select a suitable distribution board. specify the rating and number of ways.

Show the connections of the various circuits to the D.B. (this need not be detailed.)

Draw the schematic diagram of the design for the power supply to the installation in the right sequence showing all relevant parts and specifying the kind of cable or flexible wire you would recommend for the various stages and circuits of the installation.

Calculate the maximum allowable voltage drop for a 220V domestic installation.

Select a suitable distribution board. specify the rating and number of ways.

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Current Rating - Maximum current that a fuse will carry indefinitely without undue deterioration of the fuse element

Fusing Current - This is the Minimum current that will 'blow' the fuse

Fusing Factor - This is the ratio of the fusing current to the current rating

$$\text{ie fusing factor} = \frac{\text{fusing current}}{\text{current rating}}.$$

Illumination

Law of inverse square :

The amount of light which falls on one unit of the area of these surfaces is inversely proportional to the square of the distance from the source

The brightness of the surface ~~determines~~ as it ~~app~~ appears to the eye when viewed from a fixed distance depends on the amount of light that falls on it.

A stronger light will be placed further away from the surface than a weaker one to produce the same effect.

Candela : Unit of light source measurement.

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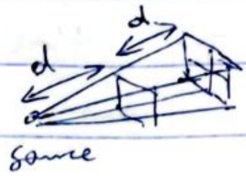
Candela : Unit of light source measurement.

Luminous intensity (symbol I)

This has to do with the strength of a source of light. and is measured in Candelas. This is a measure of the rate at which a source of light is sending out luminous energy in a given direction.

Luminous flux (ϕ) : measured in lumen

A divergent beam (cone or pyramid)



Consider a surface a distance d from the source, half way the beam length.

The light incident on the a unit surface area of the surface is inversely proportional to the ~~distance squared~~ square of the distance.

Hence $\frac{AI}{d^2} = \phi$

Given a area A and a luminous intensity I, the amount of light incident on the area A is ~~determined~~ is proportional to $\frac{AI}{d^2}$

If A & d are measured in SI unit meter.

This amount of light refered to as luminous flux is measured in lumens.

When unity = 1 lumen.

This is the amount of light falling on a unit area $1m^2$ illuminated by a source with luminous intensity of 1 candela placed a unit distance 1m away

Illumination (E) (in Lux)

This has to do with the effect of light on an object. The effectiveness of light on an object depends on the amount of light incident on the object. ie the amount of lumens I the object recieves; and actually the amount of lumens per unit area of the object. This quantity is refered to as illumination

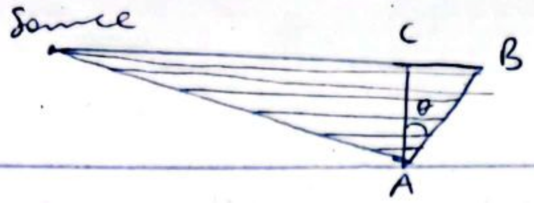
$$E = \Phi / A \quad \text{lumen}/m^2 \text{ or lux}$$

$$\text{given } \phi \text{ lumens} = \frac{A I}{d^2}$$

$$E = I / d^2 \text{ lux}$$

Cosine Law:

If the incident surface is inclined, inclined, the relation-ship is modified to accommodate the increased



The area of incident is increased by the ratio

$$\frac{AB}{AC} = \frac{1}{\cos\theta}$$ while the

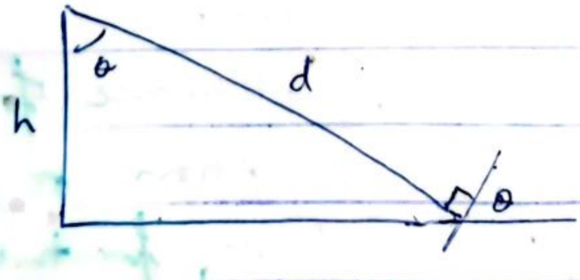
illumination is decreased by the ratio $\frac{\cos\theta}{1} = \frac{\cos\theta}{1}$

E becomes

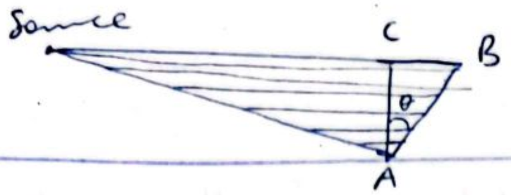
$$E = \frac{I\cos\theta}{d^2}$$

which can be modified to

$$E = \frac{Ih}{d^3} \quad \text{or} \quad E = \frac{I\cos^3\theta}{h^2}$$



given $\cos\theta = \frac{h}{d}$



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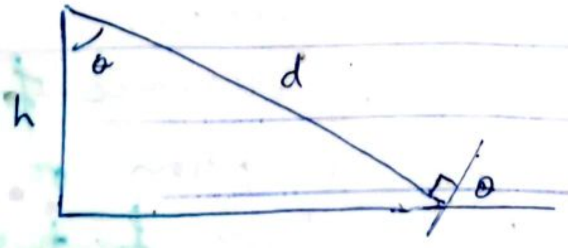


given $\cos\theta = \frac{h}{d}$

Calculation of Illumination by the 'lumen method'

$$N = \frac{E \times A}{\phi \times CU \times MF}$$

N - number of fittings needed
E - required illumination in lux
A - working area
ϕ - flux produced per fitting
CU - coefficient of utilization
MF - maintenance factor

This method assumes uniform output from lamps

The

Coefficient of utilization.
This makes allowance for losses incurred by absorption of light by walls, ceiling, floor, furniture etc

Dark colours absorb more light than pale colours. There may also be losses in the lighting fitting

Maintenence factor

This has to do with the maintenance of the installation. We assume that the installation gives only a fraction of the illumination it would give when ~~p~~ very clear.

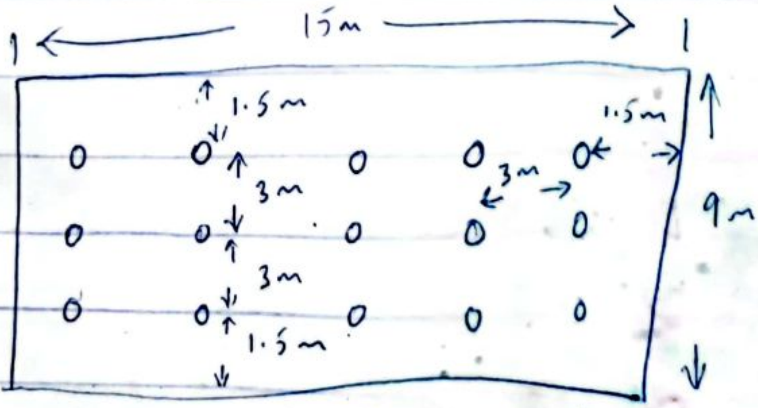
Depreciation factor is the inverse of maintenance factor ie

for a maintenance factor of 0.8 the depreciation factor = $1/0.8$ = 1.25

A light assembly shop. 15m long, 9m wide and 3m up to trusses is to be illuminated to a level of 200 lux. The utilization and maintenance factors are respectively 0.9 and 0.8. Make a scale drawing of the plan of the shop and set out the required lighting points, assuming the use of tungsten lamps and ~~disper~~ dispersive metallic reflectors. You may assume a lamp efficiency of 13 lm/W, and spacing height ratio of unity

$$\text{Lumens required} = \frac{E\,A}{M.F. \times C.U} = \frac{200 \times 15 \times 9}{0.9 \times 0.8}$$

$$= 37500$$



Required lighting points

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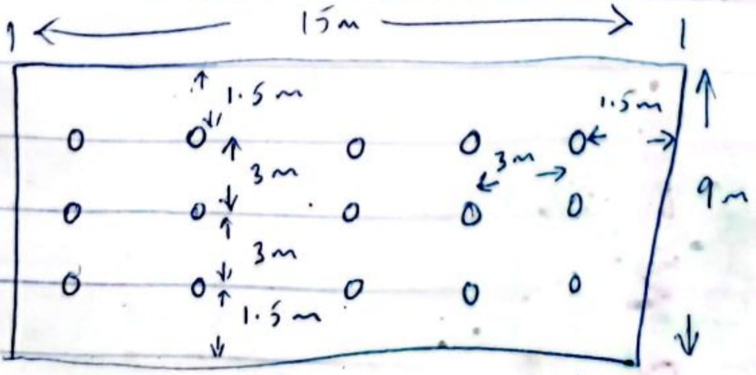


Required lighting points

Spacing - height Ratio: To reduce the problem of glare & ensure good illumination and proper maintenance (which will be affected by great height) fittings are usually fixed at roof truss or beam height.

The value of the spacing-height ratio depends upon the type of fitting and the illumination which may be specified. Once the height is decided, the ratio enables the spacing and therefore the number of fittings to be determined.

Hence

with a spacing-height ratio of unity chosen

$$S/H = 1$$

and mounting height of 3m, Spacing $S = 3 \times 1$
$= 3m$

(length wise) (width wise)

$\therefore \; 15/3 = 5$ & $9/3 = 3$

hence 15 lamps as shown in the figure

The required lighting points may be set out as in figure above

The layout diagram shows 15 lamp units for even ~~lighting~~ light distribution

With lamp units at 13 lm/W

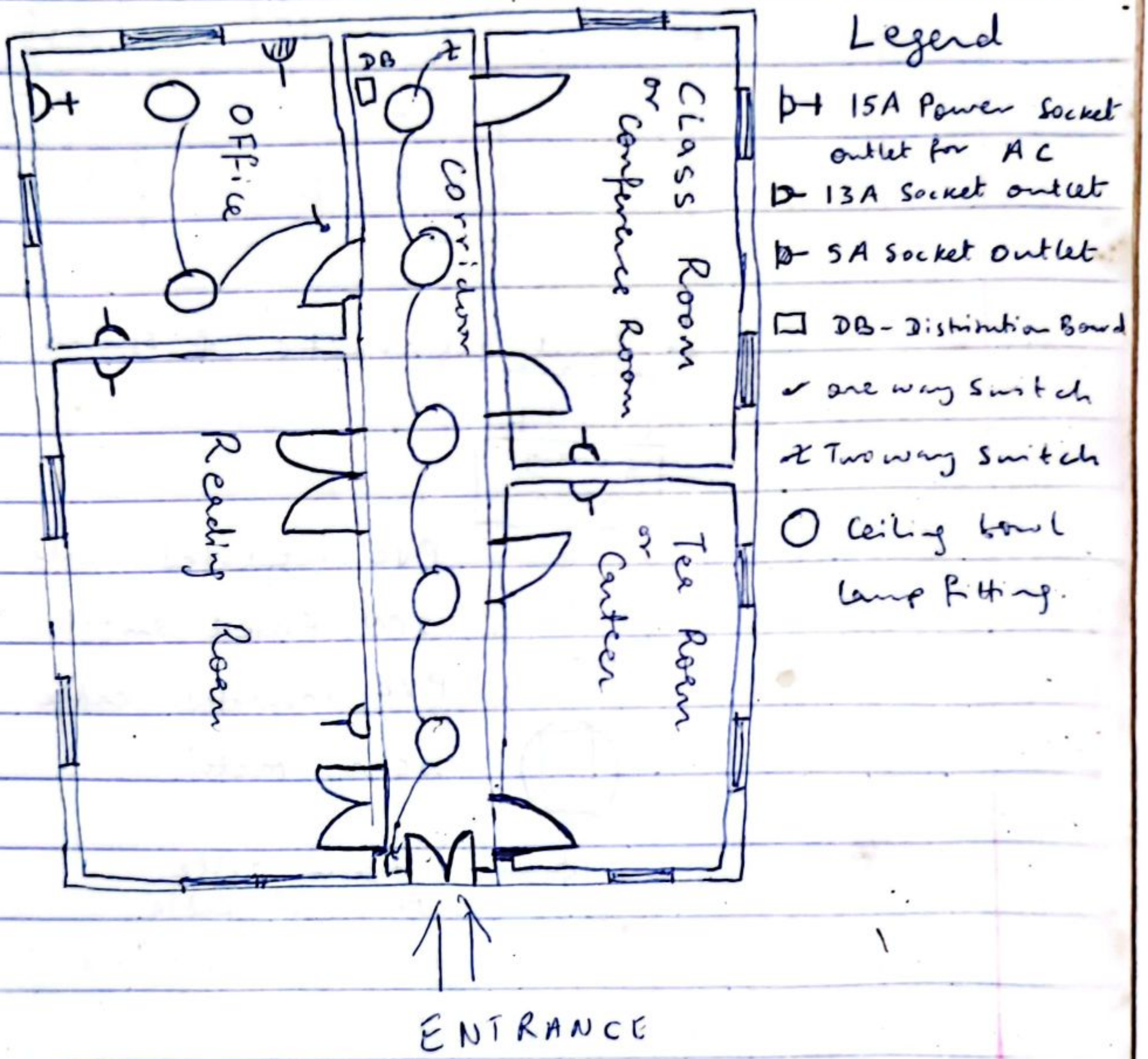
$$\text{total power} = \frac{37500}{13} = 2885\ W$$

$$\text{Power required for each lamp} = \frac{2885}{15}$$

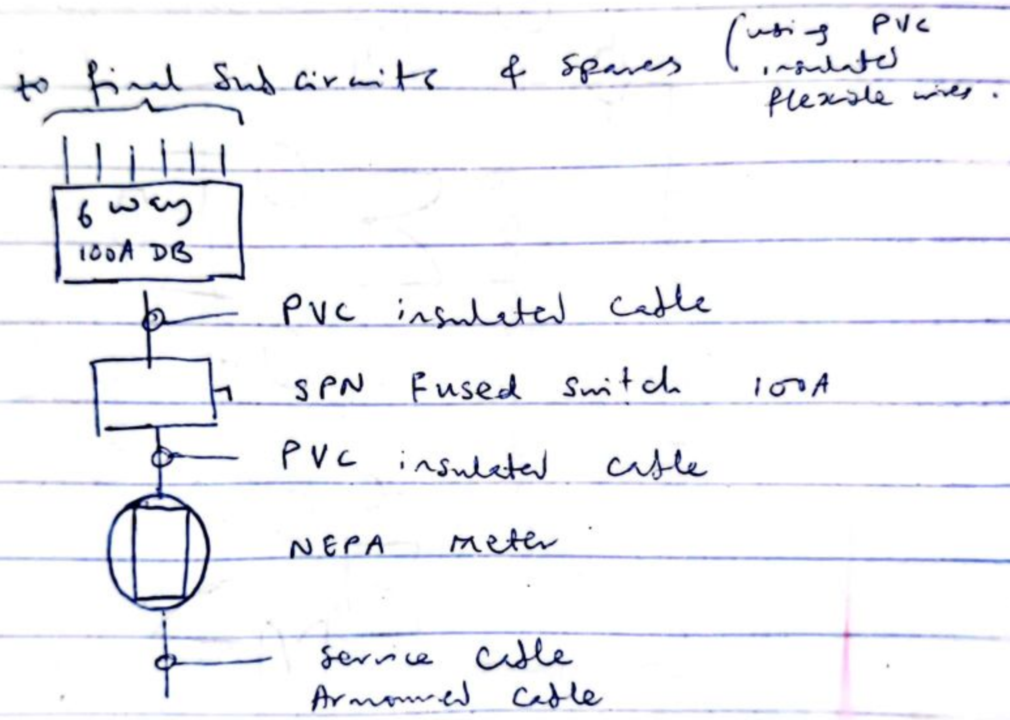
$$= 192.3\ W$$

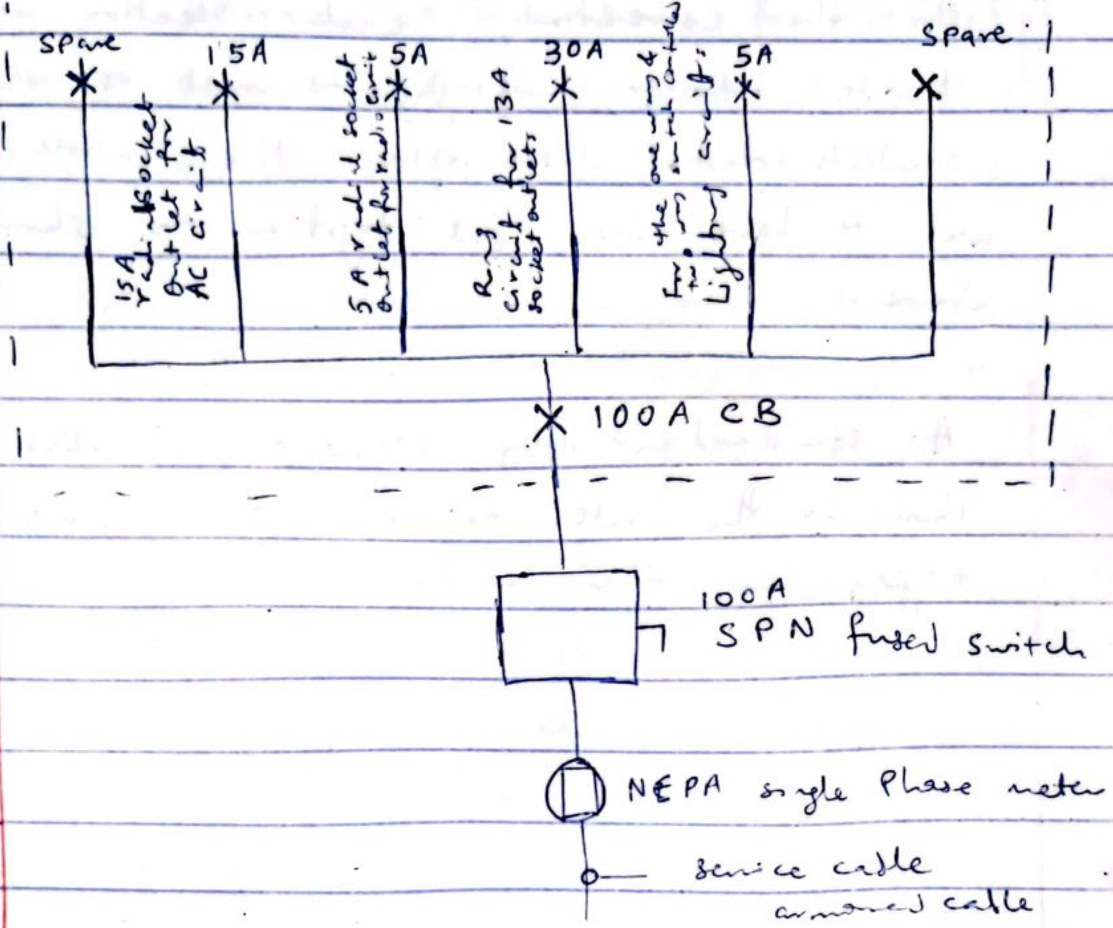
Hence fifteen 200W lamps are required.

Correction



Part of a School Complex


to final Sub circuits & spares (using PVC insulated flexible wires.
6 way 100A DB
PVC insulated cable
SPN Fused switch 100A
PVC insulated cable
NEPA meter
Service cable
Armoured cable



Check your note book for details of individual circuits. Eg. Radial circuits for 15A socket outlets, 5A socket outlet and Lamp Control for one way & 2-way Switches As well as the ring circuit for the 13A socket outlets. The Distribution board is as shown above i.e the various circuits connected to it.

these drawings include the nature location and intended use of the building of interest. The location of beams and columns, and conduits other details which would be of interest to the engineer and which will influence the design consequently,

luminous level, and Electrical facilities to be installed or provided for.

A good understanding of the proposed project would enable the Engineer determine the appropriate Electrical facilities to be installed or provided for within the limits of available resources. This calls for good client consultant relationship for proper understanding of the needs of the client as well as the recommendations of the consultant.

The luminous requirement of the various parts of the building is also determined.

In the correction, each section was to be answered singly as most of the students did. There after the whole answer was to have been put together as shown above.

A standard supply sequence is also shown in the note as well as the various cable types and their uses.

Design Considerations for residential houses, multistory, multi flat buildings; office blocks, factories & Public buildings.

Some of the design considerations are outlined below. It should be noted that the experience of the engineer is very important in design.

A Architectural & Structural drawings.

In most projects, the Electrical Engineer forms part of a design team. This team include other service engineers and the Architect. Other members of the team provide information which the engineer utilizes for his design. The Architect & Structural Engineer provide the Electrical Engineer with both architectural & structural drawings which are used by the Electrical Engineer for Electrical Services design work. Some of the information provided by these drawings include the nature location and intended use of the building of interest. The location of beams and columns, and Cantelivers. Other details which would be of interest to the engineer and which will influence the design consequently.

Luminous level; and Electical facilities to be installed or provided for.

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The luminous requirement of the various parts of the building is also ~~pp~~ determined.

Selection of fittings, luminaires, cables and other facilities.

Calculations are carried out to determine the appropriate fittings and cables as well as other facilities required to meet the design specifications laid down by the Engineer. These calculations are consistent with the principles we have studied in this course ~~of this~~ up till now. The calculations are however modified to ~~suit~~ make room for peculiarities of circumstances. The design is carried out in such a way as to meet basic standards and regulations guiding such work & design. When the appropriate number of fittings has been determined, the next step in the design procedure can then be taken.

Load analysis.

The load analysis is then

carried out making provision for diversity factors where appropriate. This has to be in line with regulating standards. The result of the load analysis will determine the service cable ~~sized~~ sizes as well as the kind of insulation required in addition to protection and control.

Protection and control

The result of the load analysis is now ~~d~~ used to determine the kind of protection and control required for the proposed building. The number & type ~~of~~ of Distribution boards and the their current and voltage specifications can be determined using the results of the load analysis. In addition to this, the switch gears are also determined in a similar way. The control ~~for~~ and protection of each final subcircuit is determined likewise. When this excersise is concluded, the

Engineer would then specify the ratings, type and number of all protective and control devices along with the associated cables for proper connection.

Appropriate drawings are produced at each stage of the design.

Bill of Quantities.

Electrical quantities are extracted from these drawings. (These bills are used for tendering by Contractors.)
The current prices ~~are also~~ these quantities are used to estimate the cost of the proposed project.

This is very important as cost is a very important factor in the Electrical Service design.

The Tests

Test are recommended by the Engineer.
These tests are carried out at the

end of the ~~las~~ project before the completed work is handed over to ensure that the design specifications are met.

During construction; provision has to be made for proper supervision.

N.B.

Provisions are made in the design for telephones, Fire alarm systems, computer systems, Television and other audio/visual aids and facilities depending on the intended use of the building.

Please read & study the following

Fluorescent lamp
Incandescent filament lamp
Tungsten filament lamps
Neon tubes
Regulations guiding most of the
topics studied so far.
Sodium-vapour discharge lamps

Select —

Stroboscopic effect of discharge lamps

At the usual alternating current supply frequency of 50HZ, a discharge lamp will be extinguished 100 times per second. Although this effect is not always noticed, it can cause problems & accidents where moving machine parts reach certain critical speeds. For eg at ~~100r/s~~ 100 rev/s a revolving part could appear to be stationary.

Earthing

This is a connection to the general mass of the earth.

The following items should be earthed

a) All metalwork of wiring systems.

b) Exposed metalwork of all apparatus

c) One part of the secondary winding, and the non-current carrying parts of the metalwork of any transformer

Parts of an earthing system

earth-continuity conductor, the consumer's, earthing terminal, the earthing lead, and the ~~earthing~~ earth electrode or its equivalent.

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Parts of an earthing system

earth-continuity conductor, the consumer's earthing terminal, the earthing lead, and the existing earth electrode or its equivalent.

Earth continuity Conductor. This is the cable or conductor which the metalwork to be earthed is connected and which itself is connected to the earthing lead by way of the consumer's earthing terminal

This could be the metal sheeting of cables, or special continuity wire enclosed in the cable sheath or metal conduit enclosing the cable. When the metal sheathing of cables or metal conduit is used as an earth continuity conductor, all joints should be soundly made and be protected where necessary against corrosion.

Earthing lead

This is the final conductor by which connection is made b/w the consumer's earthing terminal and the earth electrode or equivalent.

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This is the final conductor by which connection is made b/w the consumer's earthing terminal and the earth electrode or equivalent.

Buried electrodes

1 One or more hard-drawn bare copper rods are driven vertically into the ground surrounding the building in as damp a position as possible
Extension lengths may be available to allow of further depth penetration

2 A bare copper conductor, plate or strip, laid in a shallow trench again in the most suitable position.

Bonding

Bonding is usually confused with earthing. Bonding applies to the internal installation, and is in the form of a low resistance connection b/w any two points of the earthed system to prevent a difference of potential. Effective way to prevent earth leakage current.
Consumer's earth terminal must be properly bonded to the gas and water services as near as possible to the point of entry into the premises
Before bonding is done, the earthing must be properly tested.
Other metal objects or metalwork which one may accidentally come in contact with.

eg bath & exposed metal pipes, radiators, sinks & tanks in the absence of metal to metal joints of negligible electrical resistance.
Where bonding is not possible for some reason, the metals have to be segregated to prevent a potential difference appearing b/w them.

Tests

Verification of Polarity

Check that all single-pole switches, thermostats, and other control devices are in the live side.

The polarity test is also made to ensu that the outer contacts of centre-contac bayonet and Edison-type screw lamp-holders are connected to the neutral and that wiring has been correctly connected to plugs & socket-outlets.

Crossed ~~polarity~~

Crossed polarity, sometimes termed 'switch neutrals', is one of the major causes of severe electrical accidents.

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Crossed polarity, sometimes termed 'switched neutrals', is one of the major causes of severe electrical accidents.

Loop impedance Test

Line - earth & neutral - earth loops.

Aim: To ensure that the loop impedance is low enough to enough to ensure & allow sufficient current, in the event of an earth fault, to operate the protective device

Earth - Continuity Conductors

Earth Continuity test on the continuity conductor of ac installations.

After allowance has been made for the resistance of the leads, the value V/I when measured b/w two furthest furthest points of the installation is not to exceed 1 Ω

This value is subject to loop impedance measurement which may require lower continuity values.

Earth - leakage Circuit - breaker

To test & make sure that it will trip effectively in the event of an earth fault.

Earth - electrode Resistance

Due to an insufficiently - low earth-loop impedance, it may be necessary to check the actual resistance of the earth electrode to earth.

The electrode is disconnected from all sources of supply other than that used for testing

• It should be realised that the resistance of an electrode to the general mass of earth depends upon

a) Shape and material of electrode
b) depth of soil in which buried
c) resistivity of surrounding soil which may be seasonal and in turn dependent upon moisture content

Insulation Tests

A poor insulator has a comparatively low insulation value and vice versa

Certificates

After the testing and inspection, the IEE completion a completion and inspection certificate is issued.

Periodic testing & inspection is important & must be stressed.

Pressure Test

High voltage test.

Test certificates.

Costing certificates - of completion

Labour & Material

Site visits & programme

Regulations

Liability for defects

Labour

Pricing.

For the estimate, it is necessary to take off accurate quantities from the drawing. Where the runs are repetitive or nearly repetitive an average figure is often used. Checks, with care, should be made against cost records of previous contracts.

For the estimate proper there are four major items; namely materials, labour, overheads and profit.

The estimating engineer must be in possession of all the appropriate catalogues which will be required to be continually kept up-to-date.

It is advisable as a safeguard to add a covering statement indicating that the estimate is based on the prices ruling at the date when the tender is despatched

Prices in writing should be obtained for the larger pieces of equipment.

~~Exp~~ Except for pre-assembled units, allowance must be made for waste usually in the order of 10% in cutting conduits and 5% in cable.

Provision must also be made for unexpected diversion of runs as they may bear little relation to the straight lines, on the drawings.

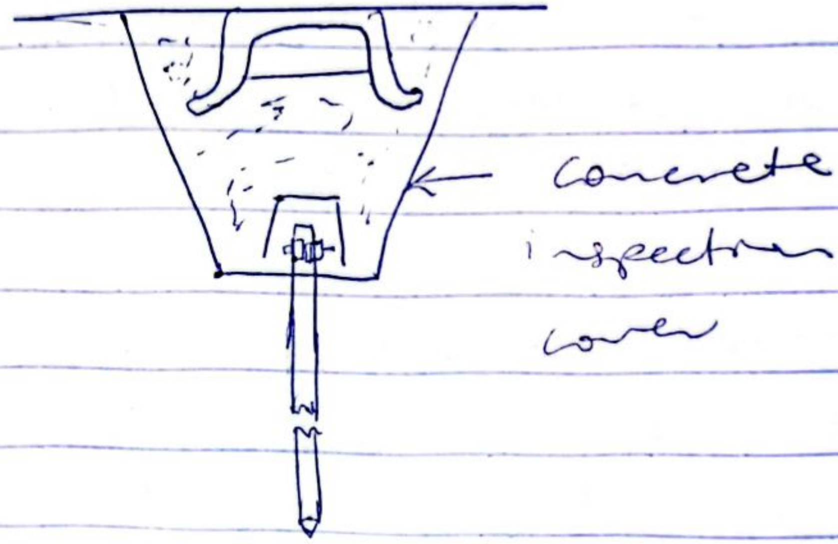
Labour

Time analysis is important using man-hours constant to determine labour charges.

other factors that influence cost include experience, skill physical fitness loyalty site condition, organisation technical training cooperation of the main contractor

Earthing

Diagram

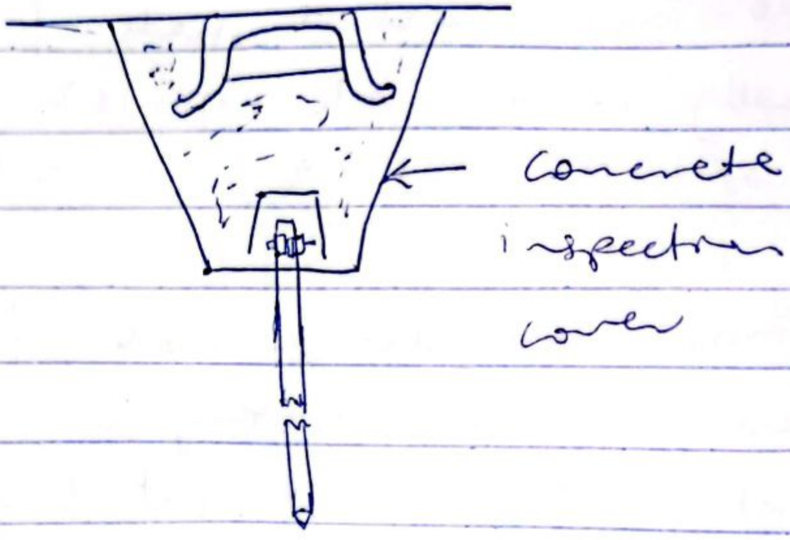


Rod type earth electrode

Protective multiple earthing is the name given to the method of protection in which the earth continuity conductor, in addition to being connected to the earthing lead on the consumer's premises is also connected to the neutral

Earthing

Diagram



Rod type earth electrode

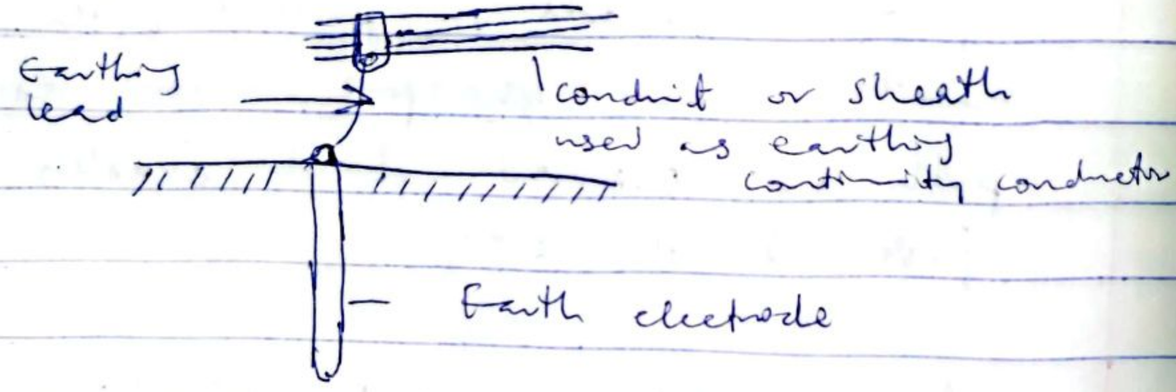
Protective multiple earthing is the name given to the method of protection in which the earth continuity conductor, in addition to being connected to the earthing lead on the consumer's premises is also connected to the neutral conductor. The effect of this is that earth fault current flows back to the source of supply by means of the neutral in parallel with the earth, and therefore a low resistance path is ensured which enables the fuse to be blown

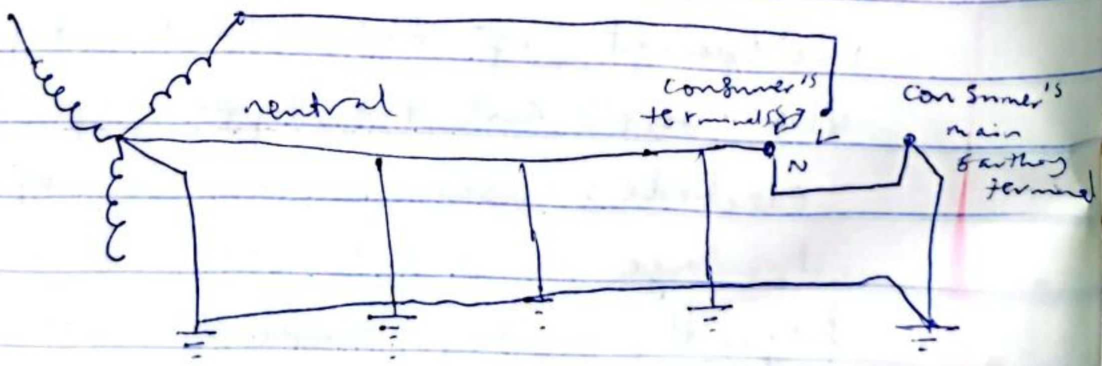
A valuable feature of this system is the fact that whether the fuse will blow or not is practically independent of the resistivity of the soil and the type of earth electrodes used. This is of considerable advantage in rural ares where it is frequently very expensive to install electrodes of sufficiently low resistance for protective purposes.

The reason for earthing is to ensure that the metalwork of electrical equipment, other than current-carrying parts, cannot have conductor. The effect of this is that earth fault current flows back to the source of supply by means of the neutral in parallel with the earth, and therefore a low resistance path is ensured which enables the fuse to be blown

A valuable feature of this system is the fact that whether the fuse will blow or not is practically independent of the resistivity of the soil and the type of earth electrodes used. This is of considerable advantage in rural areas where it is frequently very expensive to install electrodes of sufficiently low resistance for protective purposes.

The reason for earthing is to ensure that the metalwork of electrical equipment, other than current-carrying parts, cannot have a potential above earth in the event of a fault which might otherwise cause danger of an electric shock.





Bills of quantities are designed to reduce the element of chance in tendering. They may act in favour of the contractor, who might otherwise miss out essential materials, equipment or other sections of the contract.

The contract is split into a number of individual items and for costing purpose the contractor is issued with a comprehensive list. The Bill will also probably include schedule rates, which the estimator must complete, for labour

Every clause and even individual words of the specification must be studied, checked and ~~seen~~ rechecked. A missing or mistaken letter or figure of a catalogue number can make a difference of hundreds of Naira, £ or $

Not only what is in the specification but also what is left out may be of vital importance. Items such as 'rise & fall' in a period of rapid inflation and 'cutting away and making good' may easily make the difference b/w profit & loss.

Visiting the site or job is a must. Where an existing building is concerned, full details should be obtained.

It is possible to have controlled conditions and ~~&~~ can be timed and costs calculated to an exact figure.

In electrical contracting, this is not the case. No such precision is possible - nor normally desirable - with wiring jobs where full supervision is difficult and the work may be subject to the ~~ha~~ hazards of the building industry. Installation operations often have to dovetail into the work of other trades, over which the electrical contractor has no control. The work may be subject to hold-ups, or to sudden rushes, which can entail expensive overtime costs. A smooth flow of operations, while desirable is rarely attained.

Estimating

Electrical installation work is competitive contracts are usually given to firms that submit the lowest tender (lowest realistic tender). One of the major factors in operating a successful contracting business is accuracy in compiling quotations.

If prices are too high a contractor will secure no order; if too low they will

Certainly land him in trouble. Although correct estimating is vitally important, it is of course only part of running a business.

Accurate pricing requires the estimator to have a sound technical and practical background in addition to a keen business acumen.

Liability for defects

The contractor is to allow for making good within a reasonable time after receipt of written instruction from the Building Surveyors any defects of any kind which may arise within a period of Twelve Months from the date of acceptance of the completed installation by the Building Surveyor and which may be due to materials and workmanship not in accordance with this Sub-contract and are not caused by through accident, ~~mist~~ misuse or neglect.

In this connection the contractor must clearly understand that his liability for defects includes any item or article supplied by merchants or other specialist manufacturer or supplier

The contractor must therefore obtain any indemnification he deems desirable from any merchant, manufacturer or supplier before he places his order for goods.

Show an example of Bill of quantity.

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Show an example of
Bill of quantity.

Types of Cables for used)

1 PVC sheathed Cable (used for domestic 3-phase installation where they are not liable to mechanical damage)

2 PVC - insulated PVC sheathed Steel wire Armour Cable (PVC/PVC/SWA cable) for industrial and underground 3-phase power supply installation)

3 Paper - insulated lead Covered steel wire Armour cable (PI/LC/SWA Cable) for main distribution of high voltage 3-phase supply installation.

PROCEDURE FOR ELECTRICAL SERVICES DESIGN

- Get Architectural drawing & Structural drawings

- Interact with the Client to know what the building or Structure is meant for.

- Produce a plan from the Archetectural drawing.

- Carry Out the illumination and Power Point design. Have a Legend, Label and number the luminares and other installations in your design.
- Do a load analysis of the design
- Group the load into circuits
- Do a load Schedule

Load Analysis

EKASE INTERNATIONAL CONCEPTS LIMITED

General Goods: Import, Wholesales and Retails

Head Office: 68/72 Old Ojo Road, by NAID Bus Stop Agboju
Branch Office: 4 Okpara Avenue Old Park Enugu
Via monte Grappa 47 pralboino Italy

CASH INVOICE Nº 0000078

UCHENYI, KESANDU O.M
4 EZIOWELLE ST
ABAKPA NIKE ENUGU Ro, 312 Enugu Date: 31-5-2001

Qty.	Description of Goods	Rate	Amount ₦	
1	6413 Lanier model photocopying machine S/no 003373		39,000	
	Paid Cash			
	EKASE INTERNATIONAL-CONCEPTS LTD Sign. Date 31-5-2001 32 Edozien St., Uwani Enugu			
		TOTAL ₦	39,000	

Amount in words Thirty-nine thousand only

Kesandu Uchenyi
Customer's Signature

Manager's Signature

Uchenyi

ENUGU STATE UNIVERSITY OF SCIENCE AND TECHNOLOGY ESUT ENUGU
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
2011 EXAM TIME TABLE M. ENG.

DAY/DATE	TIME	COURSE TITLE	COURS CODE	INVIGILATOR
11/06/2011	10 -1 pm	Data communication and Networking	EEE 736	Engr. Mrs Abonyi
		Advanced Multivariable and Digital Control System	EEE 763	Dr. I .I Eneh /Okolo
		Power System Operation and Control	EEE 774	Dr. Ndubuisi /Obeta
18/06/2011	10 -1 pm	Mobile Wireless communication	EEE 734	Engr. Alor/Ezem
		Process Control System	EEE 768	Dr. I.I Eneh/Nnaji
		Power System Planning and Optimization	EEE 775	Dr. Ndubuisi/Ibekwe
25/06/2011	10 – 1 pm	Antenna and wave propagation	EEE 732	Dr. Eke/Okolo
		Fiber Optics and Laser technology	EEE 758	Dr. Eke/Iloh
		Power System Protection	EEE 776	Engr. Uchenyi
02/07/2011	10 – 1 pm	Robotic and Automation Engineering	EEE 766	Dr. Eneh/Ebekwe
		Advanced Design of Electrical Machine	EEE 771	Dr. Ndubuisi/Iloh

DR. I.I Eneh
H.O.D EEE D

Head of Department
P. M. B. 1660
E.N.U.G.U

Dr. I. Eke
Co-ordinator

- Draw a Schematic diagram showing protection & control.
- Specify your switch gears and cable sizes for the various sections, circuits, controls & supply.
- Produce a Bill of Quantities (Bill of Engineering Measurement and Evaluation) BEME
- Tests & Test Results.
- Earthing.

- Testing & certification by the Ministry of Mines & Power with test results & Certificates.
- Commissioning.

Certificats of Completion for payment of Contractors

OTHER TESTS

Pressure Test
High voltage Test
Insulation breakdown Test
Test Certificates
Impulse Test
Earth Leakage Test
Insulation Test.

Swing eqn

- find transient internal Voltages

Current at bus 1 using data in table 14.3 is

$$I_1 = \frac{(P_1+jQ_1)^*}{V_1^*} = \frac{3.50-j0.712}{1.030\angle -8.88^\circ}$$

$$= 3.468\angle -2.619^\circ$$

$$I_2 = \frac{1.850-j0.298}{1.020\angle -6.38^\circ} = 1.837\angle -2.771$$

$$E_1' = 1.030\angle 8.88^\circ + j0.067 \times 3.468\angle -2.619$$
$$= 1.100\angle 20.82^\circ$$

$$E_2' = 1.020\angle 6.38^\circ + j0.10 \times 1.837\angle -2.771$$
$$= 1.065\angle 16.19^\circ$$

At the infinite bus

$$E_3' = E_3 = 1.000\angle 0.0^\circ$$

hence

$$\delta_{13} = \delta_1 \quad \text{and} \quad \delta_{23} = \delta_2$$

The loads at buses 4 & 5 are represented by the admittances calculated by

$$Y_L = \frac{P_L - jQ_L}{|V_L|^2}$$

$$Y_{L4} = \frac{1.00 - j0.44}{(1.018)^2} = 0.9649 - j0.4246$$

$$Y_{L5} = \frac{0.50 - j0.16}{(1.011)^2} = 0.4892 - j0.1565$$

<u>Prefault system</u>

bus admittance matrix and which include transient reactances of the machines.

$$Y_{11} = \frac{1}{j0.067 + j0.022} = -j11.236$$

$$Y_{34} = -\frac{1}{0.007 + j0.040} = -4.2450 + j24.2571$$

The sum of the admittances connected to node 3, 4, and 5 must include the shunt capacitances of the transmission lines. So

$$Y_{44} = -j11.236 + \frac{j0.082}{2} + \frac{j0.226}{2} + 4.2450 - j24.2571 + \frac{1}{0.018 + j0.11} + 0.9649 - j\cancel{0.4246}$$

$$- j0.4246$$

$$= 6.6587 - j44.6175$$

*

$$P_{e1} = 0$$

$$P_{e2} = |E_2'| G_{22} + |E_2'||E_3||Y_{23}| \cos(\delta_{23} - \theta_{23})$$

$$= (1.065)^2 (0.1362) + (1.065)(1.0)(5.1665)$$

$$\cos(\delta_2 - 90.755^\circ)$$

$$= 0.1545 + 5.5023 \sin(\delta_2 - 0.755^\circ)$$

Therefore, while the fault is on the system, the desired swing equations (Values of P_{m_1} and P_{m_2} from Table 14.3 are

$$\frac{d^2\delta_1}{dt^2} = \frac{180f}{H_1}(P_{m_1} - P_{e_1}) = \frac{180f}{H_1} P_{a_1}$$

$$= \frac{180f}{11.2}(3.5) \quad \text{elec deg}/s^2$$

$$\frac{d^2\delta_2}{dt^2} = \frac{180f}{H_2}(P_{m_2} - P_{e_2}) = \frac{180f}{H_2} P_{a_2}$$

$$= \frac{180f}{8.0}\{\overbrace{1.85}^{P_m} - [\overbrace{0.1545}^{P_c} + \overbrace{5.5023}^{P_{max}} \sin(\delta_2 - \overset{\gamma}{0.755^\circ})]\}$$

$$= \frac{180f}{8.0}[\underbrace{1.6955}_{P_m - P_c} - 5.5023 \sin(\delta_2 - 0.75$$

$$= \frac{180f}{8.0}[\underbrace{1.6955}_{P_m - P_c} - 5.5023 \sin(\delta_2 - 0.755^\circ)] \quad \text{elec deg}/s^2$$

Table 14.4

Elements of pre fault bus admittance matrix for Example 14.9; admittances in per unit.

Bus	1	2	3	4	5
1	-j11.2360	0.0	0.0	j11.2360	0.0
2	0.0	-j7.1429	0.0	0.0	j7.1429
3	0.0	0.0	11.2841 -j65.4731	-4.2450 +j24.2571	-7.0392 +j41.3550
4	j11.2360	0.0	-4.2450 +j24.2571	6.6588 -j44.6175	-1.4488 +j8.8538
5	0.0	j7.1429	-7.0392 +j41.3550	-1.4488 +j8.8538	8.9772 -j57.2972

Table 14.5

Elements of faulted and post fault bus admittance matrices for Example above

Faulted network

Bus	1	2	3
1	0.0000 - j11.2360 (11.2360∠-90°)	0.0 + j0.0	0.0 + j0.0
2	0.0+ j0.0	0.1362 - j6.2737 (6.2752∠-88.7563°)	-0.0681 + j5.1661 (5.1665∠90.7552)
3	0.0 + j0.0	-0.681 + j5.1661 5.1665∠90.7552°	5.7986 - j35.6299 (36.0987∠-80.7564

Table 14.4

Elements of prefault bus admittance matrix for Example 14.9; admittances in per unit.

Bus	1	2	3	4	5
1	$-j11.2360$	0.0	0.0	$j11.2360$	0.0
2	0.0	$-j7.1429$	0.0	0.0	$j7.1429$
3	0.0	0.0	11.2841 $-j65.4731$	-4.2450 $+j24.2571$	-7.0392 $+j41.3550$
4	$j11.2360$	0.0	-4.2450 $+j24.2571$	6.6588 $-j44.6175$	-1.4488 $+j8.8538$
5	0.0	$j7.1429$	-7.0392 $+j41.3550$	-1.4488 $+j8.8538$	8.9772 $-j57.2972$

Table 14.5

Elements of faulted and postfault bus admittance matrices for Example above

Faulted network

Bus	1	2	3
1	$0.0000-j11.2360$ $(11.2360\angle -90^\circ)$	$0.0+j0.0$	$0.0+j0.0$
2	$0.0+j0.0$	$0.1362-j6.2737$ $(6.2752\angle -88.7563^\circ)$	$-0.0681+j5.1661$ $(5.1665\angle 90.7552)$
3	$0.0+j0.0$	$-0.681+j5.1661$ $5.1665\angle 90.7552^\circ$	$5.7986-j35.6299$ $(36.0987\angle -80.7564$

Post fault network

	1	2	3
1	0.5005 - j7.7897 (7.8058∠-86.3237°)	0.0 + j0.0	-0.2216 + j7.6291 (7.6323∠91.6638°)
2	0.0 + j0.0	0.1591 - j6.1168 (6.1189∠-88.5101°)	-0.0901 + j6.0975 (6.0982∠90.8466°)
3	-0.2216 + j7.6291 (7.6323∠91.6638°)	-0.0901 - j6.0975 (6.0982∠90.8466°)	1.3927 - j13.8428 (13.9426∠-84.2672

During the fault bus 4 is short circuited to ground. Node 4 & reference is merged.

using Node Elimination technique

$$Y_{bus} = K - LM^{-1}L^{T}$$

$$Y = \begin{bmatrix} K & L \\ L^{T} & M \end{bmatrix}$$

Inverting a matrix is avoided by eliminating a node at a time

$$\begin{array}{cc} & K \\ Y_{bus} = & \left[\begin{array}{ccc|c} Y_{11} & \cdots & Y_{1j} & Y_{1n} \\ \vdots & & Y_{kj} \; \cdots & Y_{kn} \\ Y_{k1} & & & \\ \hline Y_{n1} & \cdots & Y_{nj} & Y_{nn} \end{array}\right] \; L \\ & L^T \qquad\qquad M \end{array}$$

$(n-1) \times (n-1)$

$$Y_{bus} = \begin{bmatrix} Y_{11} & \cdots & Y_{1j} & \cdots \\ & & \vdots & \\ Y_{k1} & & Y_{kj} & \cdots \\ \vdots & & \vdots & \end{bmatrix} - \frac{1}{Y_{nn}} \begin{bmatrix} Y_{1n} \\ \\ Y_{kn} \\ \vdots \end{bmatrix} \begin{bmatrix} Y_{n1} & \cdots & Y_{nj} & \cdots \end{bmatrix}$$

$$Y_{kj(new)} = Y_{kj(orig)} - \frac{Y_{kn} Y_{nj}}{Y_{nn}}$$

As a result of node 4 merger with reference node, row & column 4 disappear. The new row 4 and column 4 (node 5) are eliminated by node elimination technique such that the Bus-admittance matrix for the faulted network is ~~reduced~~ reduced to that shown in the upper half of table 14.5

Y_{Bus} of the faulted system shows that Bus 1 decouples from the other buses during the fault and that bus 2 is ~~b~~ connected directly to bus 3. This reflects the physical fact that the short circuit at bus 4 reduces to zero the injected power into the system from generator 1 and causes generator 2 to deliver its power radially to bus 5

Under fault conditions we find by using values from Table 14.5 for the per-unit power-angle equations

* $P_{e_1} = 0$

$P_{e2} = |E_2'|^2 G_{22} + |E_2'||E_3||Y_{23}| \cdot \cos(\delta_{23} - \theta_{23})$

Nodes may be eliminated by matrix manipulation of the standard node eqn. Only those nodes at which current does not enter or leave the network can be eliminated

The column matrices are partitioned so that the elements associated with nodes to be eliminated are separated from the other elements.

The admittance matrix is partitioned so that elements identified only with nodes to be eliminated are separated from the other elements by horizontal and vertical lines

I_x is submatrix of currents entering the nodes to be eliminated ie zero since the nodes could not be eliminated otherwise

Design a house of your choice

Earthing , Test , cables

1) List 3 types of Cables & Explain their characteristics

2) What is earthing? Explain the relevance of Earthing and how it is done.

3 What tests would you Carry out after an installation has been completed. How would these tests be done & why?

4 Design a house of your choice showing all relevant Electrical features needed for a successful installation and evaluation. (Show all relevant

calculations and outline all important procedures.)

1 Design a School of your Choice (give all relevant details.)

2 What is bonding? How is it achieved in practice give examples & diagrams

3 State and explain all the differences b/w Armoured Cables & Paper - Insulated lead - Sheathed Cables

calculations and outline all important procedures.)

1 Design a School of your Choice (give all relevant details.)

2 What is bonding? How is it achieved in practice give examples & diagrams

3 State and explain all the differences b/w Armoured Cables & Paper-Insulated Lead-Sheathed Cables

Questions

1 Design the electrical Service facilities for a 3 bedroom flat. This will include all relevant Schematic diagrams; Specifications

2 Draw the plan of the top floor of the AC building showing all relevant Electrical facilities (Draw. the relevant schematic diagrams specifications and bills of quantities

3 State the test you will carry out before certifying that an electrical installation project has been completed. Explain why these tests are relevant

4 What is bonding. What is earthing Explain factors which are taken into consideration when providing earthing facilities. Write about the various earthing schemes you know. Explain the advantages

& disadvantages of each. What is the difference b/w earthing & bonding.

5 Given the table [use any table from the text book or any regulation] Calculate the voltage drop in the Corridor of your plan in the question. (2) Use your own dimensions.

6 List 5 types of cables and explain what they are used for and their various characteristics

7 Explain the two Principles you learnt about in your study of illuminations namely the inverse square law and the Cosine law. Given the Solution to question (1) Calculate the number of luminaires (type & specifications) required for one of the bedrooms. You are free to consult tables & text book.

AGu ukraine okali

Stability studies

- The ability of a system to return to normal operation after a disturbance

Transient stability studies deals with ability of the power system to remain in synchronism following major disturbances such as transmission system faults, sudden load changes, loss of generating units or line switching.

Dynamic and steady-state ~~deal~~ stability study deal with a few machines undergoing slow or gradual changes in operating conditions.

steady-state stability problems use very simple generator model which treats the generator as a constant voltage source. While the dynamic stability studies uses a model in which the excitation system and ~~turbine~~ turbine-governing system are represented along with synchronous machine models which make provision for flux-linkage variation in the machine air-gap.

The stability of the system is examined under incremental variations about an equilibrium point.

The Non-linear differential and algebraic eqns for the system can be replaced by a set of linear eqns which are then solved by methods of linear analysis to determine whether the machine or machines will remain in synchronism following small changes from the operating point.

Transient stability studies involve large disturbances which do not allow the linearization process to be used and the non-linear differential and algebraic eqn must be solved by direct method or by iterative step-by-step procedure.

Transient stability studies can be subdivided into first-swing and multiswing stability problems.

The first-swing stability is based on a reasonably simple generator model without representation of control system. Usually the time period under study is the first second following a system fault. If the machines of the system are found to remain in synchronism within the first second, the system is said to be stable. Multiswing stability problems extend over a longer study period and therefore must consider effects of generator control systems which affect machine performance during the extended time period. Machine models of greater sophistication must be represented to reflect proper behaviour.

- In all stability studies, the objective is to determine whether or not the rotors of the machines being perturbed return to constant speed operation

SWING Eqn

$$J \frac{d^2\theta_m}{dt^2} = T_a = T_m - T_e \quad N\text{-}m \qquad <>1$$

Eqn of motion of a synchronous machine.

~~J . the total moment of inertia of the rotor with respect to a stationa~~

J the total moment of inertia of the rotor masses, in kg-m^2

θ_m the ~~angle~~ angular displacement of the rotor with respect to a stationary axis in mechanical radians

t time in seconds

T_m the mechanical or shaft torque supplied by the prime mover less retarding torque due to rotational losses in N-m

T_e the net electrical or electromagnetic torque, in N-m

T_a the net accelerating torque, in N-m

~~J~~	~~the total moment of inertia of the rotor with respect to a stationary~~
J	the total moment of inertia of the rotor masses, in kg-m^2
θ_m	the ~~angle~~ angular displacement of the rotor with respect to a stationary axis in mechanical radians
t	time in seconds
T_m	the mechanical or shaft torque supplied by the prime mover less retarding torque due to rotational losses in N-m
T_e	the net electrical or electromagnetic torque, in N-m
T_a	the net accelerating torque, in N-m

$\theta_m = \omega_{sm} t + \delta_m$ <> 2

where

θ_m is measured with respect to a stationary reference axis on the stator. This is a measure of the rotor angle.

ω_{sm} is the synchronous speed of the machine in mechanical radians per second and δ_m is the angular displacement of the rotor in mechanical radians from the synchronously rotating reference axis.

differentiate eqn above eqn <> 2

$$\frac{d\theta_m}{dt} = \omega_{sm} + \frac{d\delta_m}{dt} \quad <> 3$$

$$\frac{d^2\theta_m}{dt^2} = \frac{d^2\delta_m}{dt^2} \quad <> 4$$

ω_{sm} is a constant hence the result above.

rotor angular velocity $d\theta_m/dt$ is constant only when $d\delta_m/dt$ is zero

This constant value is the Synchronous Speed.

$\therefore$ $d\delta_m/dt$ represents the deviation of the rotor speed from Synchronous speed or synchronism. The unit of measurement is mechanical radians per seconds.

subs eqn <>4 in eqn <>1

$$J\frac{d^2\delta_m}{dt^2} = T_a = T_m - T_e \quad N\text{-}m \quad <>5$$

let $\omega_m = \frac{d\theta_m}{dt}$

Power = Torque x angular velocity

$P = T\omega$

multiply eqn <>5 by ω_m

$$J\omega_m \frac{d^2\delta_m}{dt^2} = P_a = P_m - P_e \quad W$$

P_m — shaft power input to the machine less rotational losses (Prime mover Power supplied)

P_e — electrical Power crossing its air-gap

P_a = accelerating Power accounts for unbalance b/w the two quantities.

$J\omega_m$ — angular momentum of the rotor

at synchronous speed, ω_{sm}; $J\omega_m \equiv M$

$J\omega_{sm} \equiv M \equiv$ called inertia Constant of the machine.

unit [~~Joul Jn~~ Joule - seconds per mechanical radian]

$$M \frac{d^2\delta_m}{dt^2} = P_a = P_m - P_e \quad W$$

Remember that M is not a constant since ω_m is not always equals synchronous speed.
However ω_m & ω_{sm} are usually close when machine is stable.

H - constant

$$H = \frac{\text{stored kinetic energy in megajoules at synchronous speed}}{\text{machine rating in MVA}}$$

$$H = \frac{\frac{1}{2} J \omega_{sm}^2}{S_{mach}} = \frac{\frac{1}{2} M \omega_{sm}}{S_{mach}} \quad MJ/MVA$$

~~S_{mac}~~ S_{mach} is 3ϕ rating of the machine in MVA multiply eqn <>5 by ω_m

$$J\omega_m \frac{d^2\delta_m}{dt^2} = P_a = P_m - P_e \quad W$$

P_m — shaft power input to the machine less rotational losses (Prime mover Power supplied)

P_e — electrical Power crossing its air-gap.

P_a = accelerating Power accounts for imbalance b/w the two quantities.

$J\omega_m$ — angular momentum of the rotor

at synchronous speed, ω_{sm}; $J\omega_m \equiv M$

$J\omega_{sm} \equiv M \equiv$ called inertia constant of the machine.

unit [~~Jouel~~ ~~Jn~~ Joule-seconds per mechanical radian]

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$$H = \frac{\frac{1}{2} J \omega_{sm}^2}{S_{mach}} = \frac{\frac{1}{2} M \omega_{sm}}{S_{mach}} \quad MJ/MVA$$

~~S_{mac}~~ S_{mach} is 3ϕ rating of the machine in MVA

$$M = \frac{2H}{\omega_{sm}} S_{mach} \quad \text{MJ/mech rad}$$

$$\cancel{\frac{2H}{\omega_{sH}}}$$

$$\frac{2H}{\omega_{sm}} \frac{d^2\delta_m}{dt^2} = \frac{P_a}{S_{mach}} = \frac{P_m - P_e}{S_{mach}}$$

Since δ_m & ω_{sm} are in mechanical radians & mechanical radians/second

This is the swing eqn:

$$\frac{2H}{\omega_s} \frac{d^2\delta}{dt^2} = P_a = P_m - P_e \quad \text{per unit}$$

< > 6

Provided δ and ω_s have consistent units which may be mechanical or electrical degree or radians

H & t have consistent units since megajoules per megavolt ampere is in units of time in seconds and P_a, P_m and P_e must be in per unit on the same base as H.

when m subscript is associated with ω, ω_s and δ, it means mechanical units are used; otherwise electrical units are implied.

Hence ω_s is synchronous speed in electrical units.

for a frequency of f hz (hertz)

$$\frac{H\, d^2\delta}{\pi f\, dt^2} = P_a = P_m - P_e \quad \text{per unit} \quad \langle 7 \rangle$$

where

δ is in electrical radians

$$\frac{H}{180f}\frac{d^2\delta}{dt^2} = P_a = P_m - P_e$$

if δ is in electrical degrees

The swing eqn <> 6 governs the rotational dynamics of the synchronous machine in stability studies

Notice that it is a second order differential eqn & can be expressed as

$$\frac{2H}{\omega_s}\frac{d^2\delta}{dt^2} = P_m - P_e \quad \text{per unit}$$

$$\frac{d\delta}{dt} = \omega - \omega_s$$

When the swing eqn is solved, expression for δ is obtained, as a function of time. The curve is called the swing curve of the machine. This curve shows if the machine will retain synchronism in the event of a disturbance.

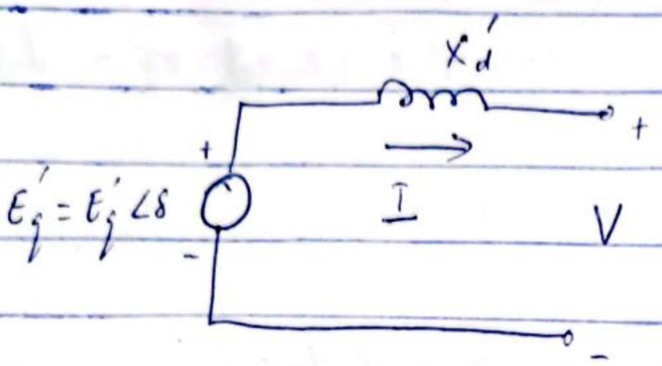
Consider a simplified Generator model, such that

X_q = Quadrature axis synchronous reactance

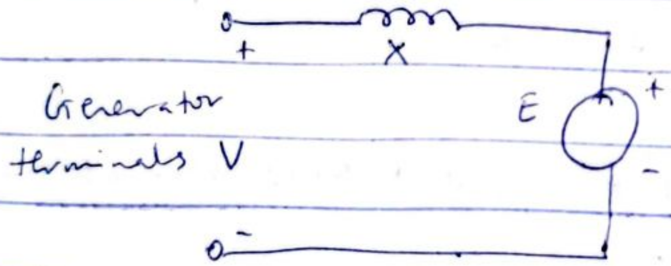
If the transient direct axis reactance $X'_d = X_q$.

$$E'_q = E_q$$
$$= jX_q I + V$$
$$= jX'_d I + V$$

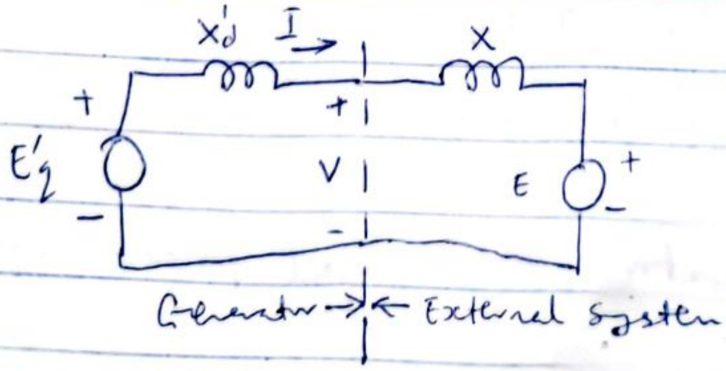
V - Generator terminal phasor voltage



simplified transient generator model



System equivalent circuit.



Simplified generator/system model for transient stability

Parastroica — restructuring of the economy.

$$P_m - P_e = \frac{H\,d^2\delta}{\pi f\,dt^2}$$

where

$$P_m = \text{constant}$$

$$P_e = \frac{E_q' E}{X_d' + X} \sin\delta$$

$$\omega_r = \omega_{sync} \quad \text{So that} \quad \frac{d\omega_r}{dt} = 0$$

NB

$$S = VI^* \qquad = V\left[\frac{E-V}{jX_d}\right]^*$$

if

$V = V\angle 0^\circ$ = Generator terminal voltage

$E = E\angle\delta$ = Generator internal voltage

δ = Power angle

$$S = \frac{VE}{X_d}\angle 90^\circ - \delta - j\,V^2/X_d$$

$$= \frac{VE}{X_d}\sin\delta + j\left[\frac{VE}{X_d}\cos\delta - \frac{V^2}{X_d}\right]$$

Parastroica - restructuring of the economy.

$$P_m - P_e = \frac{H d^2\delta}{\pi f dt^2}$$

where

$$P_m = \text{constant}$$

$$P_e = \frac{E_q' E}{X_d' + X} \sin\delta$$

$\omega_r = \omega_{sync}$ So that $\frac{d\omega_r}{dt} = 0$

NB

$$S = VI^* = V\left[\frac{E-V}{jX_d}\right]^*$$

if

$V = V\angle 0°$ = Generator terminal voltage

$E = E\angle\delta$ = Generator internal voltage

δ = Power angle

$$S = \frac{VE}{X_d}\angle 90° - \delta - j\,V^2/X_d$$

$$= \frac{VE}{X_d}\sin\delta + j\left[\frac{VE}{X_d}\cos\delta - \frac{V^2}{X_d}\right]$$

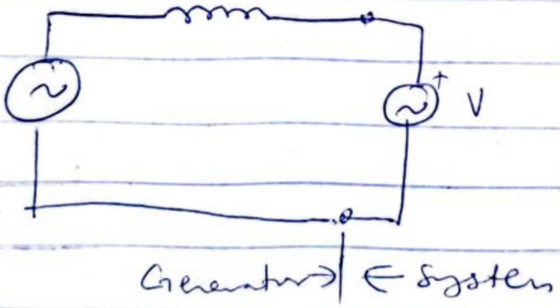
hence

$$P = \mathrm{Re}\,[S]$$

$$= \frac{VE}{X_d} \sin\delta$$

$$Q = \mathrm{Im}\,[S]$$

$$= \frac{VE}{X_d} \cos\delta - \frac{V^2}{X_d}$$



$$E = jX_d I + V$$

when $P_m = P_e$ the system is said to be in equilibrium.

i.e. $\frac{d^2\delta}{dt^2} = 0$

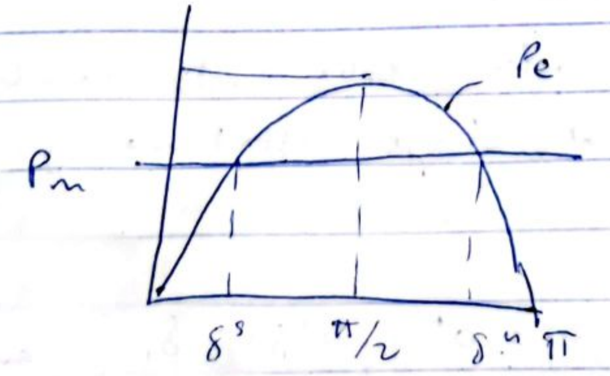
when

$P_e > P_m$ $d^2\delta/dt^2$ is negative

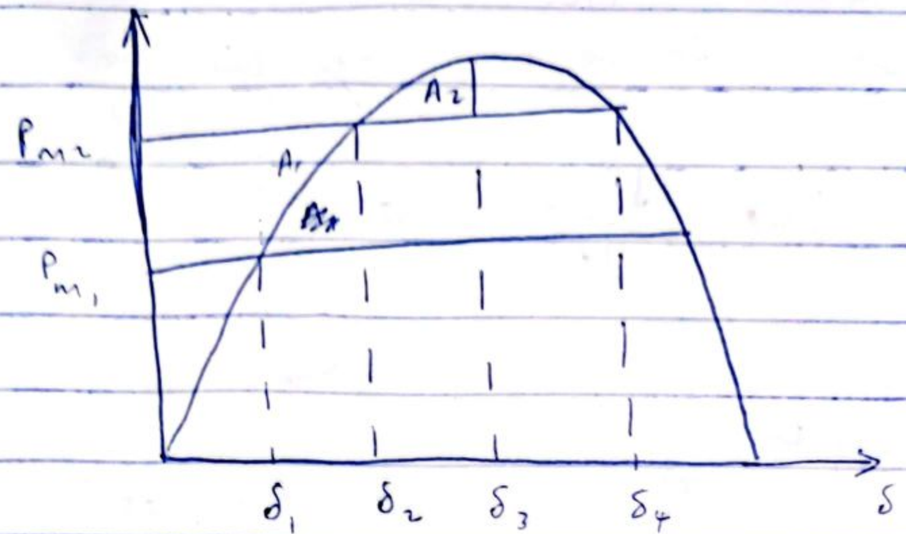
& decreases δ

The reverse is the case for $P_m > P_e$

hence the terms stable & unstable equilibria



P_m & P_e vs δ



System reaction to a sudden change in P_m

Consider a normal operation such that

$$P_m = P_{m_1} \quad \& \quad \delta = \delta_1$$

If at $t=0$ P_m is changed to P_{m_2}

Taking rotor inertia into consideration, δ will not change instantaneously.

Hence

at $t = 0^+$, $\delta = \delta_1$ and $P_m > P_e$

this causes rotor acceleration & δ increase

This continues until $\delta = \delta_2$

Beyond δ_2 , $P_m < P_e$

i.e for the rest interval $\delta > \delta_2$ $P_m < P_e$

Causing rotor deceleration

and the rotor stops at δ_3 & swings back towards δ_2

At this stage,

given

$$\frac{d}{dt}\left[\frac{d\delta}{dt}\right]^2 = 2\frac{d\delta}{dt}\cdot\frac{d^2\delta}{dt^2}$$

{Make $\frac{d^2\delta}{dt^2}$ the subject of the eqn i.e multiplying both sides by dt and divide both sides by $d\delta$ & divide both sides by 2}

$$\frac{d^2\delta}{dt^2} = \frac{d\left(d\delta/dt\right)^2}{2\,d\delta} \qquad \overset{\wedge}{\vee}\,1$$

~~if we substitute this in eqn $\overset{\wedge}{\vee}$ 1~~

If we substitute eqn $\overset{\wedge}{\vee}$ 1 into eqn < > 7

we get

$$\frac{H}{2\pi f}\, d\left(\frac{d\delta}{dt}\right)^2 = (P_m - P_e)\, d\delta$$

Integrating

$$\left(\frac{d\delta}{dt}\right)^2 = \frac{2\pi f}{H}\int_{\delta_0}^{\delta} (P_m - P_e)\, d\delta \qquad \hat{\check{2}}$$

eqn $\hat{\check{2}}$ shows that the area b/w P_m & P_e functions, is proportional to the square of $d\delta/dt$, with the angular velocity relative to the reference velocity

Since kinetic energy is also proportional to angular velocity squared, we can assume that these areas or conclude that these areas are related to kinetic energy relative to a rotating reference

Hence as observed already, when $P_m > P_e$ the rotor is accelerating and the rotor acquires an energy of A_1 which must be offset by A_2 acquired when the rotor decelerates $(P_m < P_e)$

Eqn < > 7 suggest that as a result of this inbalance, the rotor will oscillate about δ_2 indefintly In practice it eventually dampers out

The rotor stabilizes at the new equilibrium value δ_2

The more the increase in P_m, the more the swing on δ.

The maximum swing is at δ_3 ie the value of δ_3 increases.

There reaches a stage beyond which stability can not be restored ie for $\delta > \delta_4$, $P_m > P_e$

The rotor accelerates causing δ to increase and stability is lost.

If there is a change in P_e due to fault or switching....

The P_e curve changes & causes a disturbance

Notice that eqn 2 tells us that the expression is integrated from $\delta = \delta_0$ to $\delta =$ some arbitrary value

ie the rotor is not swinging

at the beginning ie when $\delta = \delta_0$, $d\delta/dt = 0$

When the right hand $= 0$, $d\delta/dt$ is also zero ie at this stage, the rotor has stopped.

$$A_1 = \int_{\delta_1}^{\delta_2} (P_m - P_e)\, d\delta$$

for stability there has to be enough negative area to $(-A_2)$ in the interval $\delta_2 < \delta < \delta_4$ to offset this motion

If there is a change in P_e due to fault or switching....

The P_e curve changes & causes a disturbance

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$$-A_{2max} = \int_{\delta_2}^{\delta_4} (P_m - P_e)\, d\delta$$

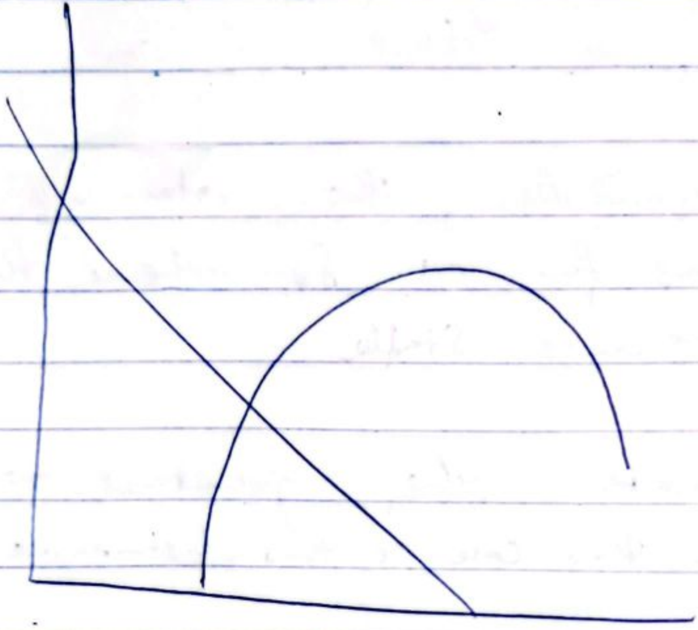
If $A_{2max} > A_1$, the rotor will not swing as far as δ_4 hence the system remains Stable

To calculate the greatest rotor swing, for this case ie this disturbance

We remember that the rotor is stopped when $A_2 = A_1$

$$\int_{\delta_2}^{\delta_3} (P_m - P_e)\, d\delta = \text{Value calculated for } A_1$$

This may result in a non linear eqn which could be solved iteratively.



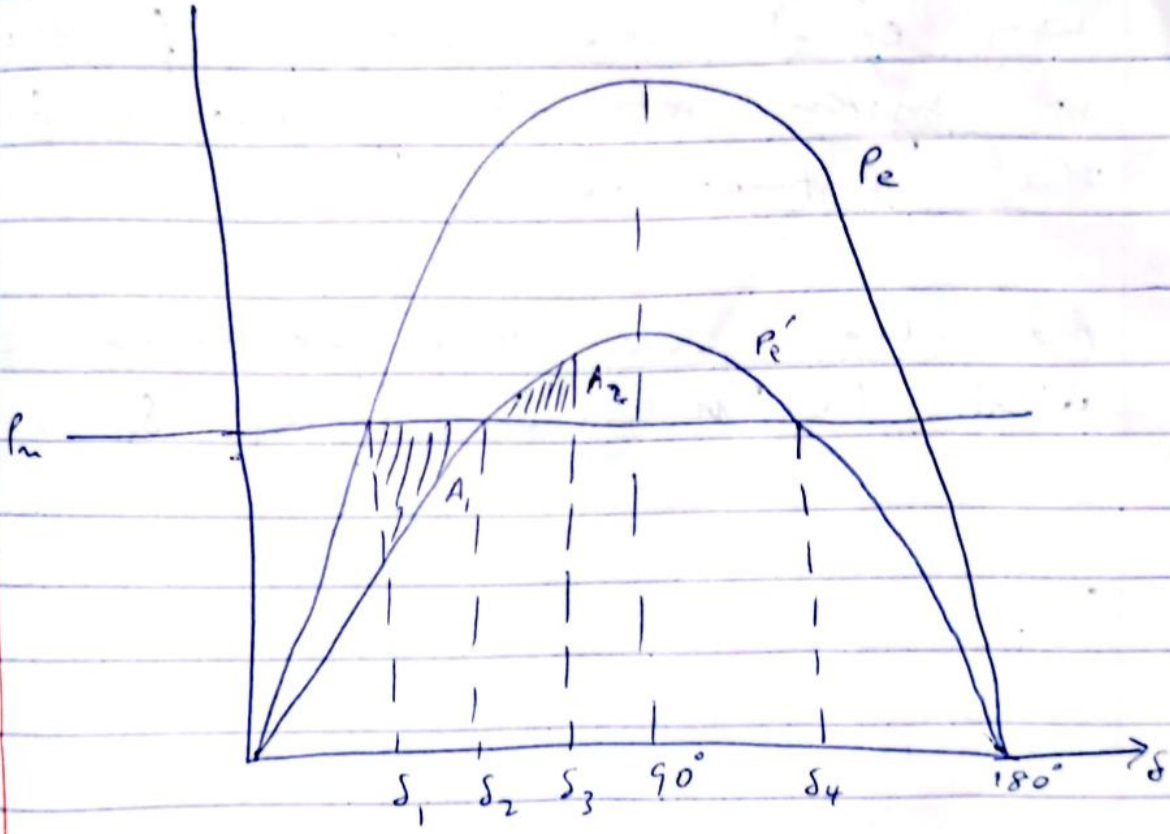
At $t = 0^-$

$$P_e = \frac{E E_q'}{X_d' + X} \sin\delta$$

at $\delta = \delta_1$, $P_{e_1} = P_m$

This gives the equilibrium angle δ_1 performance point before the fault. Hence $P_{e_1} = P_m$

In the event of a fault, there is a change in P_e due to change in line impedance due to the fault ie



value of X changes hence P_e changes.

Notice from the diagram that δ_2 & δ_4 are the points when ~~$P_m = P_e'$~~ $P_e' = P_m$

Hence solving for δ in the new expression for P_e' equated to P_m gives δ_2 & δ_4

These values are used to determine using equal area criteria if the ~~the~~ system retains synchronism following the disturbance

And also given the particular case, what the maximum swing δ_3 is.

Example.

Single Line to Ground fault on an Unloaded Generator.

Below is the circuit diagram of a single line-to-ground fault on an unloaded Y-connected generator with its neutral grounded through a reactance as shown below. Where phase 'a' is the one on which the fault occurs. The relations to be developed for this type of fault will apply only when the fault is on phase 'a', however, this should not cause any problem since the phases are labelled arbitrarily and any phase can be designated as phase 'a' phase 'a'. The conditions at the fault are expressed by the following eqns

$I_b = 0 \quad I_c = 0 \quad V_a = 0$

since I_a is grounded. & on no load condition

With $I_b = 0$ and $I_c = 0$ the symmetrical components of current are given by

$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_a \\ 0 \\ 0 \end{bmatrix}$$

So that I_{a0}, I_{a1} and I_{a2} each equal $I_a/3$ and

$$I_{a1} = I_{a2} = I_{a0} \qquad \text{M 1}$$

Substituting I_{a1} for I_{a2} and I_{a0} in eqn B1 below

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix}\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} \qquad \text{B1}$$

Remember total zero. sequence impedance is given by $Z_0 = 3Z_n + Z_{g0}$ where Z_{g0} is the zero sequence impedance per phase of generator & Z_n is the impedance b/w neutral and ground.

(Remember the positive sequence is the only active network)

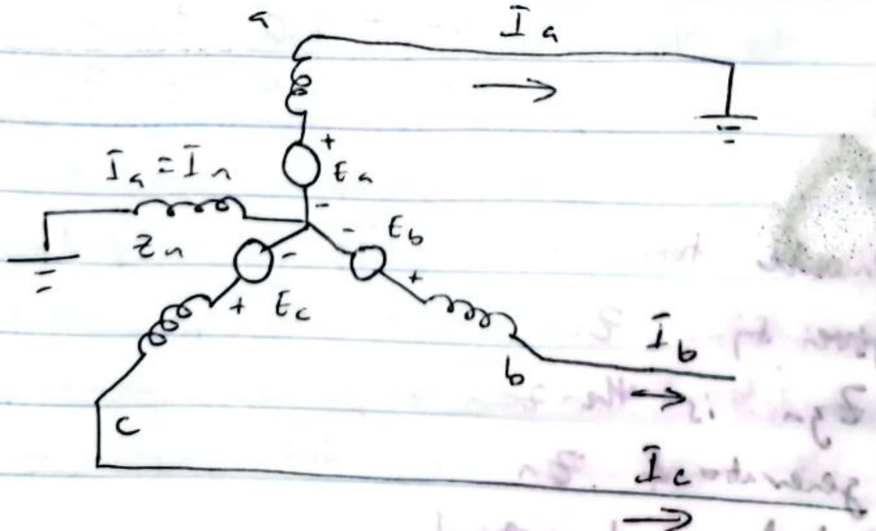
We then have

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix} \begin{bmatrix} I_{a1} \\ I_{a1} \\ I_{a1} \end{bmatrix}$$

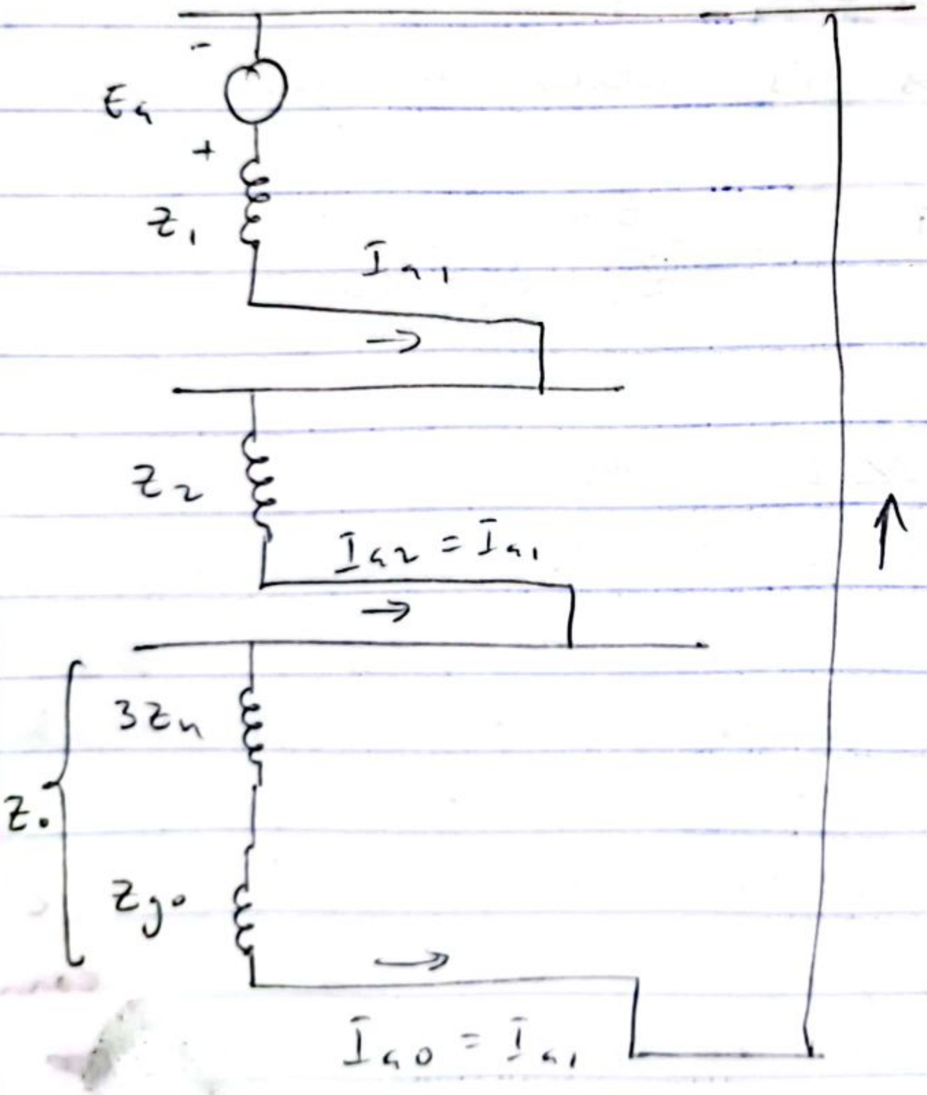
Evaluate the matrix above to get an Equality of two ~~stat~~ column matrices.

Premultiply both column matrices by the row matrix [1 1 1] gives

$$V_{a0} + V_{a1} + V_{a2} = -I_{a1}Z_0 + E_a - I_{a1}Z_1 - I_{a1}Z_2 \qquad B2$$

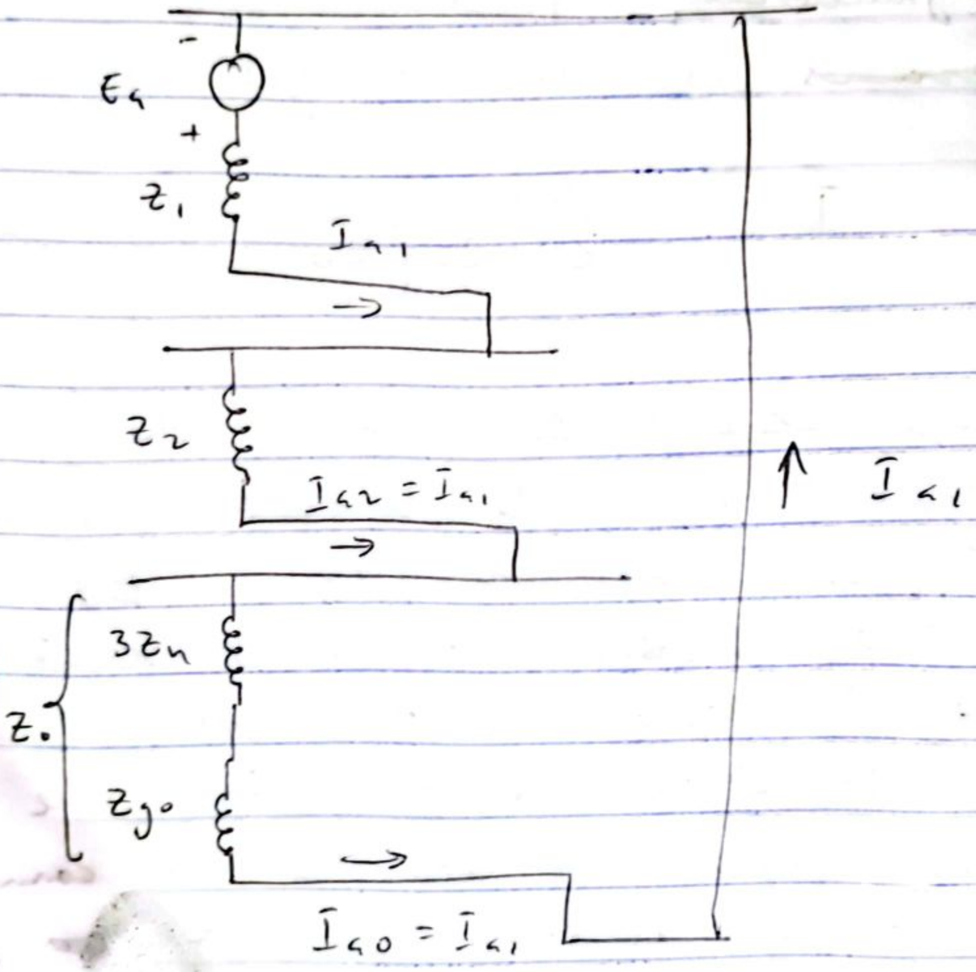


Circuit diagram for a single line-to-ground fault on phase a at the terminal of an unloaded generator whose neutral is grounded through a ~~reactor~~ reactance



connection of the sequence networks of an unloaded generator for a single line-to-ground fault on phase a a at the terminals of the generator.

generator whose neutral is grounded through a ~~reactor~~ reactance



connection of the sequence networks of an unloaded generator for a single line-to-ground fault on phase a at the terminals of the generator.

Since $V_a = V_{a0} + V_{a1} + V_{a2} = 0$

because $V_a = 0$ & when resolved to its symmetrical components remains 0. eqn B2 ~~because~~ is solved to get I_{a1}

$$I_{a1} = \frac{E_a}{Z_1 + Z_2 + Z_0} \qquad M2$$

eqn M1 & M2 are the special eqns for a single line-to-ground fault. They are used with Eqn B1 & the symmetrical component relations to determine all the voltages and currents at the fault. If the three sequence networks are connected in series as shown in the ~~ee~~ fig above we see that the currents & voltages resulting therefrom satisfy the eqns above; since the three sequence impedances are the in series with voltage E_a

With this connection, the voltage across each sequence network is the symmetrical component of V_a of that sequence.

If the neutral is not grounded, the zero sequence network is open-circuited and Z_0 is infinity

Since eqn 11.2 shows that I_{a1} is zero when Z_0 is infinite, I_{a2} and I_{a0} must be zero. Thus no current flows in line a since I_a is the sum of ~~the~~ its components all of which are zero. The same result can be seen without the use of symmetrical components since inspection of the circuit shows that no path exists for the flow of current in the fault unless there is a ground at the generator neutral

A Salient pole generator without dampers is rated 20MVA 13.8kV and has a direct-axis subtransient reactance of 0.25 per unit. The negative and zero-sequence reactances are respectively, 0.35 and 0.10 per unit. The neutral of the generator is solidly grounded. Determine the subtransient current in the generator and the line to line voltages for subtransient conditions when a single line to ground fault occurs at the generator terminals with the generator operating unloaded at rated voltage : Neglect resistance.

Solution # On a base of 20MVA, 13.8 kV, $E_a = 1.0$ pu (line voltage of generator)

Since internal voltage = terminal voltage at no load

hence in P.U.

$$I_{a_1} = \frac{E_a}{Z_1 + Z_2 + Z_0} = \frac{1.0 + j0}{j0.25 + j0.35 + j0.10}$$

$$= -j1.43 \text{ pu}$$

$$I_a = 3I_{a_1} = -j4.29 \text{ p.u.}$$

$$\text{Base Current} = \frac{20{,}000}{\sqrt{3} \times 13.8} = 837 \text{ A}$$

Sub transient current in line a is

$$I_a = -j4.29 \times 837 = -j3,590A$$

The symmetrical components of the voltage from point a to ground are

$$V_{a1} = E_a - I_{a1}Z_1 = 1.0 - (-j1.43)(j0.25)$$

$$= 1.0 - 0.357 = 0.643 \text{ p.u.}$$

$$V_{a2} = -I_{a2}Z_2 = -(-j1.43)(j0.35)$$

$$= -0.50 \text{ pu.}$$

$$V_{a0} = -I_{a0}Z_0 = -(-j1.43)(j0.10)$$

$$= -0.143 \text{ pu}$$

Line to ground voltages are

$$V_a = V_{a1} + V_{a2} + V_{a0} = 0.643 - 0.50 - 0.143 = 0$$

$$V_b = a^2 V_{a1} + aV_{a2} + V_{a0}$$

$$= 0.643(-0.5-j0.866) - 0.50(-0.5+j0.866) - 0.143$$

$$= -0.322 - j0.557 + 0.25 - j0.433 - 0.143$$

$$= -0.215 - j0.990 \text{ pu}$$

$$V_c = aV_{a1} + a^2 V_{a2} + V_{a0}$$

$$= 0.643(-0.5+j0.866) - 0.50(-0.5-j0.866) - 0.143$$

$$= -0.322 + j0.557 + 0.25 + j0.433 - 0.143$$

$$= -0.215 + j0.990 \text{ pu.}$$

Line to line voltages are

$$V_{ab} = V_a - V_b = 0.215 + j0.990 = 1.01\angle 77.7^\circ \text{ pu}$$

$V_{bc} = V_b - V_c = 0 - j1.980 = 1.980\angle 270^\circ$ pu

$V_{ca} = V_c - V_a = -0.215 + j0.990 = 1.01\angle 102.3^\circ$ pu

Since E_a (generated voltage to neutral) = 1.0pu, the above line to line voltages are in pu. of this value

Hence post fault line voltages are

$V_{ab} = 1.01 \times \frac{13.8}{\sqrt{3}} \angle 77.7^\circ = 8.05\angle 77.7^\circ$ kV

$V_{bc} = 1.98 \times \frac{13.8}{\sqrt{3}} \angle 270^\circ = 15.78\angle 270^\circ$ kV

$V_{ca} = 1.01 \times \frac{13.8}{\sqrt{3}} \angle 102.3^\circ = 8.05\angle 102.3^\circ$ kV

Before the fault the line voltages were balanced & equals 13.8kV

With $V_{an} = E_a$ as reference, Prefault voltages are

$V_{ab} = 13.8\angle 30^\circ$ kV $V_{abc} = 13.8\angle 270^\circ$ kV

$V_{ca} = 13.8\angle 150^\circ$ kV