LECTURE NOTES

SWITCHGEAR AND PROTECTIVE DEVICE

6th SEMESTEER

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CHAPTER-1

Introduction to switchgear :—

* What is switchgear?

→ The apparatus which is used to directing, controlling, switching & protecting the electrical circuit and electrical equipment is known as switch gear.

→ As switch gear essentially consist of switching and protecting device such as :- (i) Switches
(II) Fuses
(III) Circuit breakers
(IV) Relays

→ During normal operation permits to switch on & off generator, transmission and distribution and other electrical equipments.

(1.1) The essential features of switch gear were basically divided into 5 types such as :- (i) Complete reliability.
(ii) Quick operation.
(iii) Absolute certain discrimination.
(iv) Provision for manual control.
(v) Provision for instrument.

(i) Complete reliability :—

→ The demand for reliable switchgear, has become ~~off~~ up~~at~~most important due to the ongoing trend of interconnection and growing capacity of generating station.

→ Switch gear is added to the power system to improve the reliability, when fault occure in any part of power system. the switching must operate to isolate faulty section from reminder circuit.

(ii) Quick Operation :—

→ When fault occures on any part of the power system, the switchgear must operate quickly so that no damage is done to the generator transformer and other equipments by the short circuit current.

(iii) Absolute certain discrimination :—

→ When fault occure in the any part of the power system the switchgear must be able to discriminate between the faulty section & healthy section.

(iv) Provision for manual control.

→ A switch gear must have povision for manual control in case of control fails the nescessary operation can be carried out through manual control.

(v) Provision for instruments :—

→ Provision for instrument may be in the form of ammeter or voltmeter on the unit itself or the necessary current or voltage transformer for connecting to the main switch board or a separate instrument panel.

1.2 Switch Gear Equipment

→ The switch gear cover all the wide range of equipment concerned with switching and interupting current under both normal and abnormal current.

→ It includes :— (i) Switches
(ii) Fuses
(iii) Circuit Breaker
(iv) Relay

→ Other equipments are lighting arresstor, isolator, current transformer etc.

(i) Switches:—

→ It is a device which is used to open or close an electrical circuit in convient way and can be used under full load or no load condition but it can't interrupt fault current.

→ Switches are may be classified into 3 types such as :—

(a) Air break switch

(b) Oil switch

(c) Isolator/disconnecting switch

(a) Air break switch:—

→ In the air switch it is designed to open a circuit on load.

→ In order to quench arc that occure on opening such a switch special arcing.

→ Air break switches are generally used outdoor for circuit of medium capacity such as line supply and industrial load form a main transmission line or feeder.

(b) Oil switch:—

→ The contact of such switches are open under oil usually transformer oil.

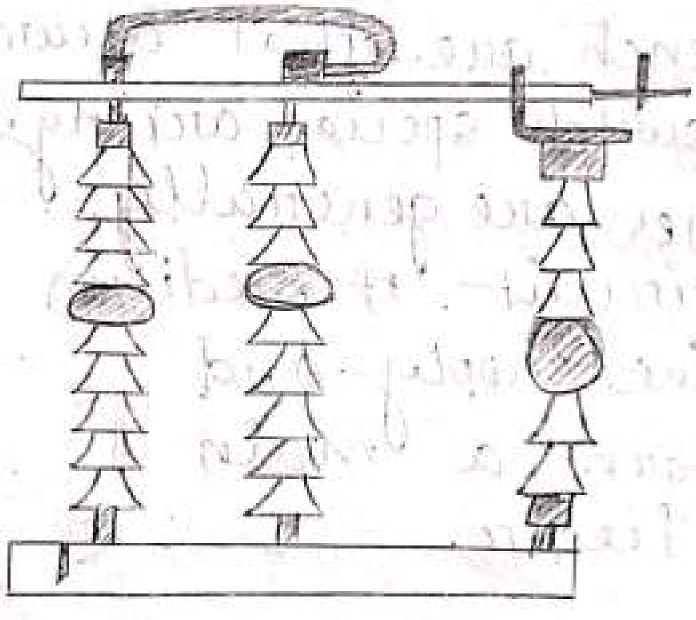
→ The effect of oil to cool and quench the arc that tends when the circuit is opened.

→ These switches are used for circuit at high voltage and large current carrying capacity.

(b) Isolator / Disconnecting switch :-

→ This switch are design to open the ckt under no load. It's main function is to isolate one portion of the circuit from the other.

→ The slots are generally used on both side of the ckt breaker in order to repair and replacement of circuit-breaker.



(ii) Fuse :—

→ A fuse is a short piece of wire or thin stripe which melts when excessive current flow through it for sucessive time.

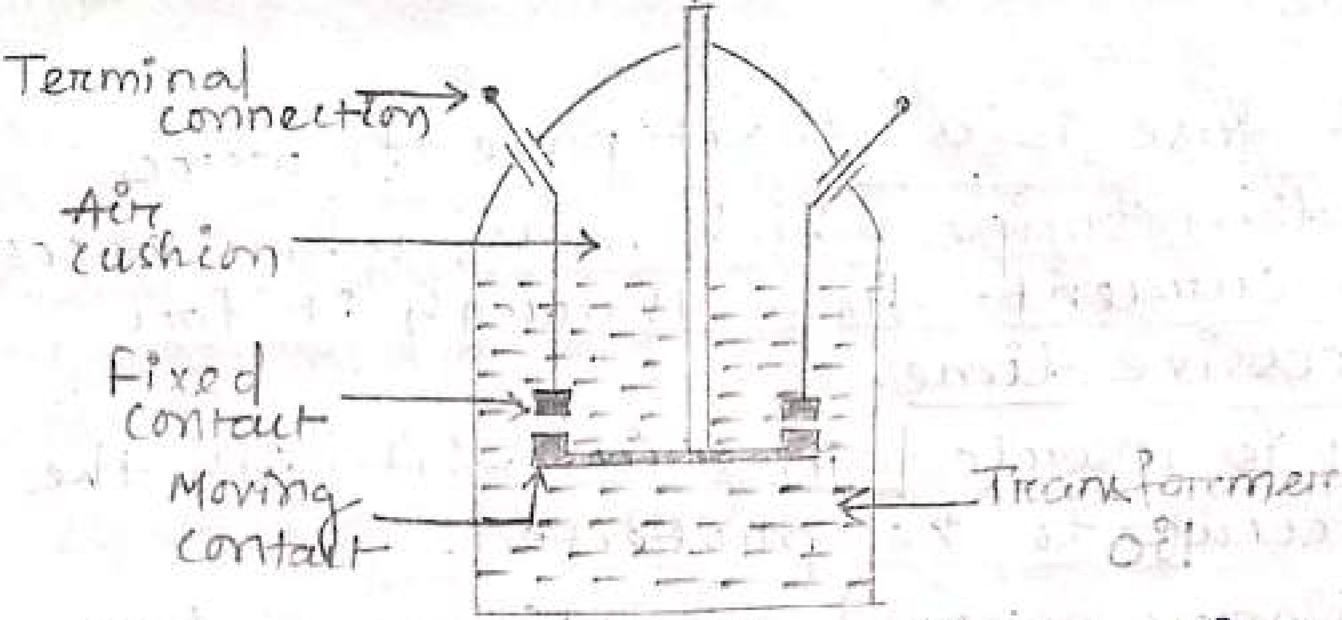
→ It is inserted in series ~~what~~ with the circuit to be protected.

→ Under normal operationg condition the fuse element at temperature below melting point therefore it carries the normal load current without overheating, however during short circuit the current through the fuse element increases beyond its rated capacity, this raises the temperature and fuse element melts and disconnecting the circuit by protecting it.

(iii) Circuit Breaker :—

→ A circuit breaker is an automatically operated electrical switch design to protect an electrical circuit form the damage cause by over load of electricity or short circuit

→ A circuit breaker function is it detect a fault connection of ckt & intercepting immediately electricity



(iv) Relay:- A relay is a device which detect the fault and supplies information or command to the circuit breaker for circuit interruption.

→ The primary winding of the current transformer which is connected in series with the circuit to be protected. The primary winding often consist of the main conductor itself.

→ The second circuit ? of current transformer connected in the relay operating point.

→ The third is tripping circuit which consist of a force of supply, trip coil of circuit breaker and relay.

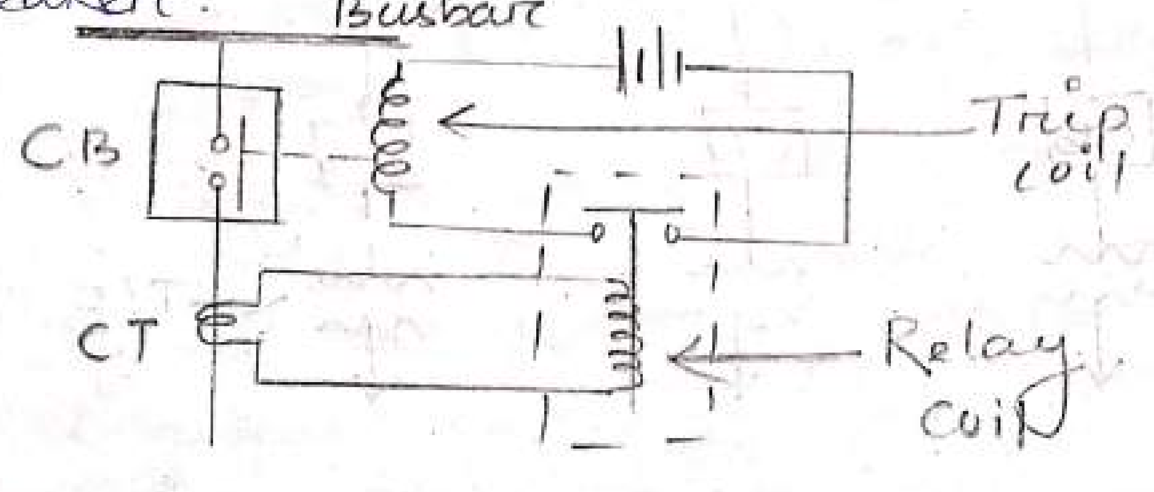
* Operation :-

→ Under normal load condition the emf of secondary winding of current transformer is small and the current flowing in the relay operation coil is insufficient to close the contact.

→ This keeps the trip coil of circuit breaker unenergised. Consiquently, the contact of circuit breaker remain close and it carry normal load current.

→ When fault occure a large current flows through the primary of current transformer. This increases the secondary emf and hence the current flow through the relay operating current.

→ The ~~to~~ relay contact are closed and trip coil is energised and it open the contact of circuit breaker.



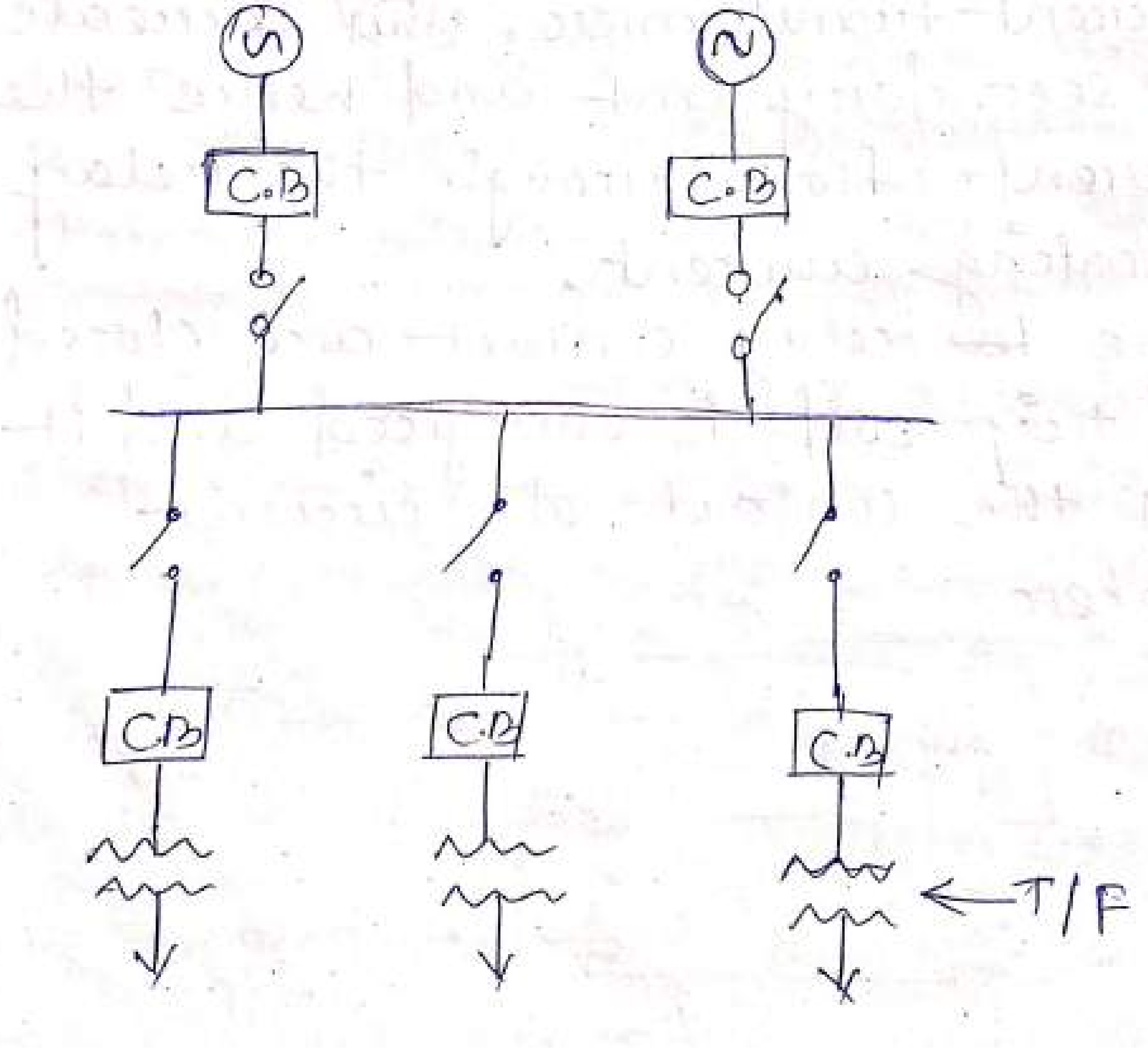
1.3 BusBar Arrengments

→ Busbar are copper rods or thin wall tubes and operated at constant voltage.
Some busbar arrengments are single busbar system which is sectionalisation.

* single busbar syetem :-

→ The single busbar system has a simpler in design and used in the power system.

→ It is also used in small outdoor station having relatively few incoming or outgoing feeders and line.



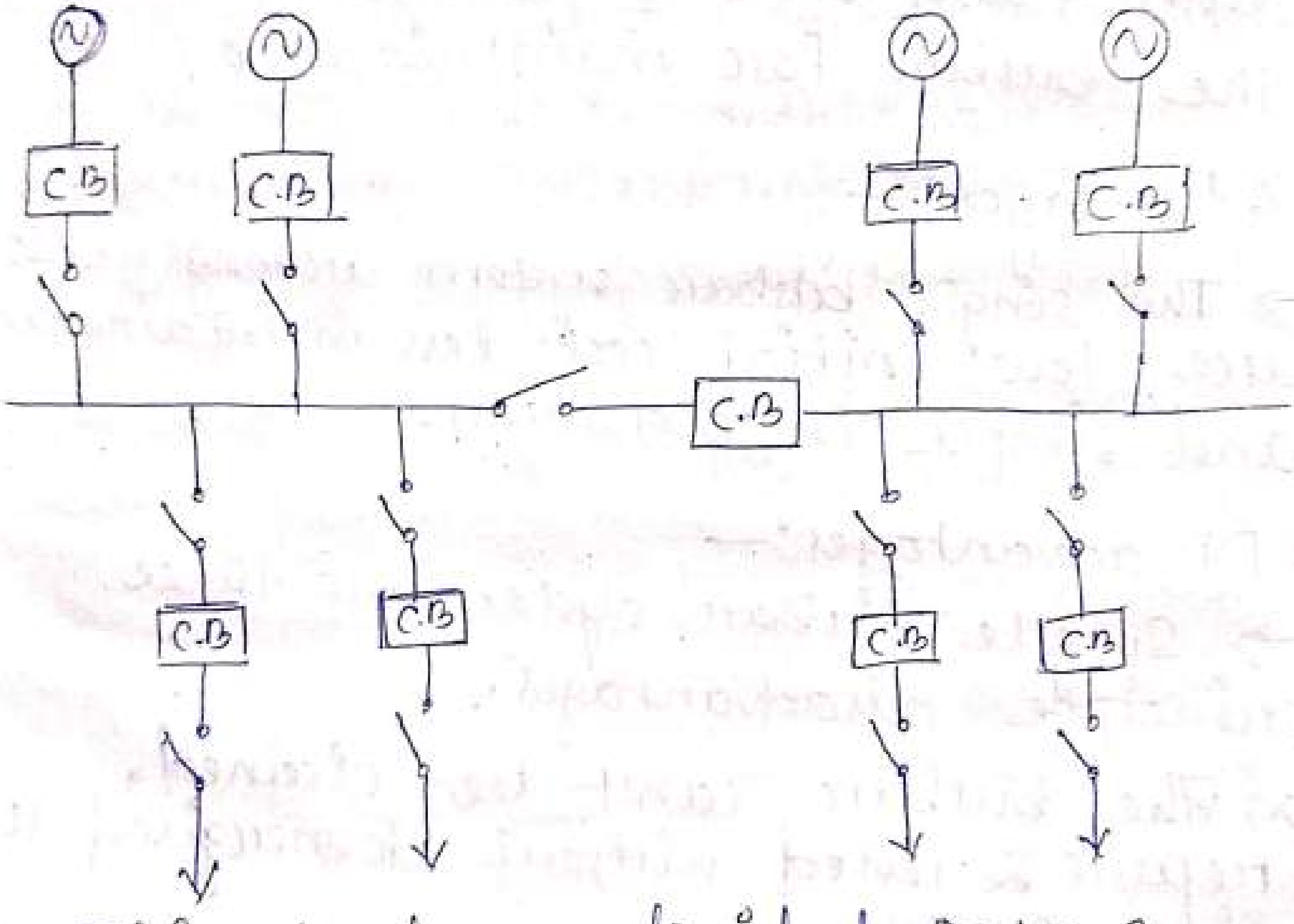
→ In above fig. shows the single busbar system for a typical power station.
→ The generators outgoing lines and transformers are connected to the busbar and each generator and feeder is controlled circuit breaker.
→ Isolator permits to isolate generators, feeders, and circuit breakers from the busbar for maintainance.

* Advantages:—
→ The single busbar system arrangements are low initial cost less maintainance and simple in operation.

* Disadvantages:—
→ Single busbar system are three principle disadvantages.
(a) The busbar can't be cleaned, repair & tested without deenergised the whole system.
(b) If a fault occures on the busbars itself, there is a complete interruption of supply.
(c) Any fault on the system is fed by all the generating capacity, resulting a very large fault current.

Single busbar system with Sectionalised

→ In a large generating station where ~~sevela~~ several units are installed, it is common practise to sectionalise the bus, so that the fault any section of of busbar will not caused complete shutdown.



→ This busbar divided into 2 sections connected by circuit breaker and isolators.

* Advantages:—

→ If a fault occurres on any section of busbar, that section can be isolate without affecting the supply one section.

→ Secondly if any fault occure on any feeder the fault current is much lower than with on sectionalise busbar. This permits the use of circuit breaker of lower capacity of the feeder.

→ Thirdly, repairs and maintainance of any section of the busbar can be carried out by decreasing that section only, eliminate the posibility of complete shutdown.

⇒ Duplicate busbar system:—

→ In a large station it is important that breakers and maintainance should interfear as soon as possible continuity of supply.

→ In order to achieve this objective, duplicate busbar system is used in important station.

→ Such a system consist of 2 busbar, a main busbar and a pair busbar.
→ Each generator and feeder may be connected to either busbar with the help of bus coupler, which consist of a circuit breaker and isolator.

(1.4) Switchgear accomodation :-

→ It is neccessary to housed in the power station and substation in a such a way so as to safeguard personal during operation and maintainance and ensure that the effects of fault of any section of the gear are contained to a limited region.
→ Depending upon the voltage to be handled, switch gear may be classified into,

(i) Outdoor type.
(ii) Indoor type.

(i) Outdoor Type :-

→ For voltage beyond 66 KV, switchgear equipments are installed outdoor. It is because for such voltages, the clearance between conductors and space require for switches, C.B & other equipments become so great that is not economical to install all such equipments indoor.

(ii) Indoor Type :-

→ For voltages 66KV, switchgear is generally installed indoor because of economic ~~cond~~ consideration.

→ The indoor switch gear is generally metal clad type and all leave parts are completely enclosed in an earthed metal casing.

→ The primary object of this practice is ~~denote~~ definite localisation and restriction of any fault to its place of origin.

1.5 Short-circuit :—

→ When ever a fault occure on a network such that a large current flows on one or more phases, a short circuit is occured.

→ When short-circuit occure, a heavy current called short-circuit current flows through the circuit & the voltage at fault point is reduced to zero.

* Cause of short-circuit :—

→ A short-circuit in a power system caused due to internal and external effects.

(i) Internal effects :— This are caused by breakdown of equipment or transmission lines from deterioration of insulating of a generator, transformer etc.

→ Such trouble may be due to ageing of insulation, inadequate design or improper installization.

External Effect :— It causing short circuit include insulation failure due to lighting surge, over-loading of equipment causing excessive heating, mechanical damage by public etc.

(1.6) Short-Circuit Current :—

→ Most of the failure in the power system lead to short-ckt fault and cause heavy current to flow on the system.

→ The calculation of these short-circuit current are important for the following reasons :—

(i) A short circuit in a power system is cleared by CB or a fuse.

(ii) The magnitude of short circuit current determines the setting & sometimes the type and location of protective system.

(iii) The magnitude of short-circuit current determines the size of protective reactors which must be inserted in the system, so that the C.B. as able to withstand the fault current.

(iv) The calculation of short-circuit current enable us to make proper selection of the associated apparatus (i/e busbars, CT), so can they are withstand the force that arise due to the occurance of short circuit.

(1.7) Fault in Power System:—

→ A fault occures when two or more conductor that normally operate with potential difference come in contact with each other.

→ This fault may be caused by sudden failure of a piece of equipment, accidental damage or short circuit due to over heat, or by an insulation to failure by lighting.

→ The fault in 3ϕ system classified into two types:—

(i) Symmetrical
(ii) Unsymmetrical.

(i) Symmetrical fault:—

→ That fault gives rise to symmetrical fault current equal fault current with 120° displacement is called symetrical fault.

→ The common example of symmetrical fault is when all the three conductors of a 3ϕ line are brought togather simulteneously into short-circuit condition.

(ii) Unsymmetrical fault:—

→ Those fault which gives rise to unsymmetrical current (i/e current with unequal displace-ment) are called unsymmetrical fault.

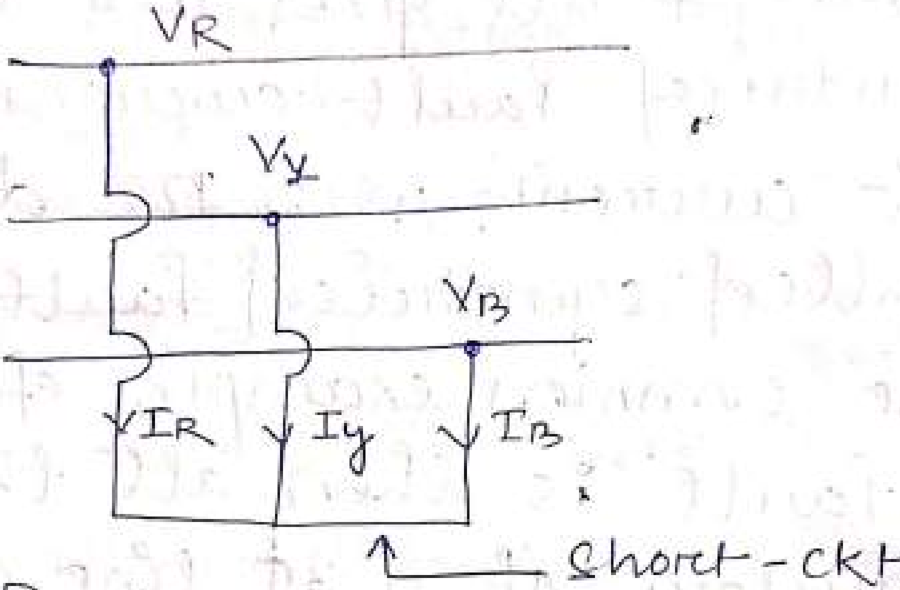
→ Unsymmetrical faults are:—

(a) Single line – ground fault.
(b) line – line fault.
(c) Double line – ground fault.

CHAPTER-2

FAULT CALCULATION

2.1, Symmetrical fault on 3ϕ system



→ These fault on the power system which gives to rise in symmetrical fault current i/e equal fault current in line with 120° displacement, is called symmetrical fault.

→ This faults occures when all three conductores of a 3-ϕ line are bought togather simulteneously into a short circuit condition.

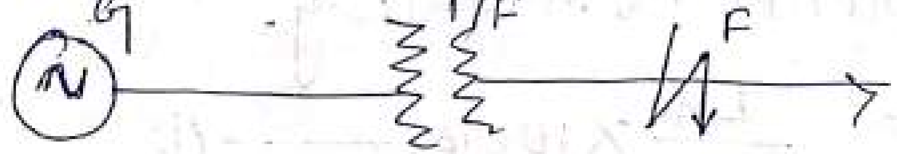
→ In the above fig. the fault current I_R, I_Y, I_B will be equal in magnitude with 120° displacement among them.

→ Because of balanced nature of fault in one phase need to be consideration, in calculation since condition in other two phases will similar.

→ The symmetrical fault rarely occure in the practice as majority of fault are on unsymmetrical on nature.

→ The symmetrical fault as the more severe and imposes more heavy duty on the circuit breaker.

2.3 Limitation of fault current.



→ When short-circuit occure in any point of a system, it is limited by the impedance of the system upto the point of fault.

→ Thus referring a the above fig, if a fault current occure in the feeder at point F, then the short circuit current from the generating station will have a value limited by the impendance of generator and transformer and impendance of line between the generator & point of fault.

2.3 Percentage of Reactance:—

→ The reactance of generators, transformer, reactor etc is usally expressed in percentage reactance to permit rapid short circuit calculation.

→ Percentage of reactance is define as the n of total phase voltage dropped in the circuit when full-load current is flowing.

$$\% x = \frac{Ix}{V} \times 100 \quad \text{——— (1)}$$

I = full load current

V = phase voltage

x = reactance

% x = percentage reactance

⇒ Alternatively, percentage of reactance can also be expressed in term of KVA and KV as under,

We know,

$$\%x = \frac{Ix}{V} \times 100$$

$$\Rightarrow x = \frac{\%x \times V}{100 I}$$

$$\Rightarrow x = \frac{\%x \times V \times V}{100 \times I \times V}$$ (Voltag multiple)

$$\Rightarrow x = \frac{\%x \times \frac{V}{1000} \times \frac{V}{1000} \times 1000}{100 \times \frac{V}{1000} \times I}$$

$$\Rightarrow x = \frac{\%x \times (KV)^2 \times 10}{KVA}$$

$$\Rightarrow \%x = \frac{KVA\, x}{10 (KV)^2} \quad \text{—— (2)}$$

→ If the x is only reactance in circuit, then Isc (shortckt current)

$$\Rightarrow I_{sc} = \frac{V}{x}$$

$$\Rightarrow I_{sc} = V \times \frac{I}{V \times \%x} \times 100 \quad \left(\because x = \frac{V \%x}{I \times 100}\right)$$

$$\Rightarrow \boxed{I_{sc} = \frac{I\, 100}{\%x}}$$

Q, If the percentage of reactance 30%. and the full load current flow in the circuit is 70A, calculate the Isc, when that the only element in the circuit?

Ans:- Given data

$\% X = 30\%$

$I = 70A$

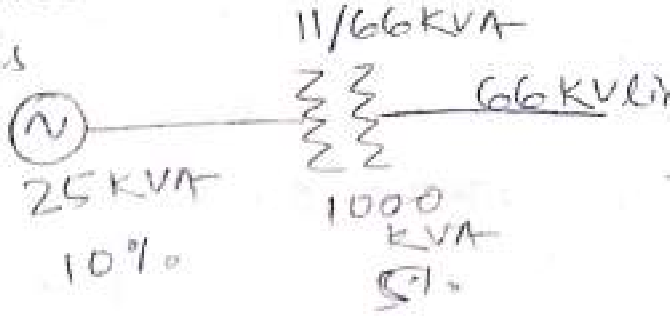
then, $I_{sc} = \frac{70 \times 100}{30}$

$= 23.33 \times 10$

$= 230.33$ amp. (ans)

Q2, The fact that the value of base KVA doesnot affect the short-circuit current needs illustration consider a 3-ϕ transmission line operating at 66KVA and connected through a 1000KVA transformer with 5% reactance to a generating station busbar. The generator is of 2500KVA with 10% reactance. The single line diagram is shown in below, suppose a short circuit fault between three phase occure?

(i) Suppose 2500KVA as the common base KVA. On this base value, the reactance of the various elements are,



Reactance of transformer,

$$= \frac{5 \times 2500}{1000} = 12.5\%$$

Reactance of ~~trans~~ generator

$$= \frac{\%x \times \text{base KVA}}{\text{rated KVA}}$$

$$= \frac{10 \times 2500}{2500} = 10\%$$

Total percentage $= 10 + 12.5 = 22.5\%$

then,

Full load current (I),

$$= \frac{2500 \times 1000}{\sqrt{3} \times 66 \times 10^3} = 21.87A$$

→ Short circuit current (Isc)

$$= \frac{I \times 100}{\%x} = \frac{21.87 \times 100}{22.5} = 97.2A$$

(2.5) Short-circuit KVA

→ The product of normal system voltage and short-circuit current at the point of fault expressed in KVA is known as short-circuit KVA.

→ Let V = Normal phase voltage in volts

I = Full load current in ampere in base KVA

%x = then percentage reactance of system on base KVA upto the fault point.

$$I_{sc} = \frac{I \times 100}{\% x}$$

∴ Short circuit KVA for 3ϕ circuit,

$$\Rightarrow \frac{3 V I_{sc}}{1000} = \frac{3 V I}{1000} \times \frac{100}{\% x}$$

$$= \boxed{\text{Base KVA} \times \frac{100}{\% x}}$$

(2.6) Reactor control of short-circuit current.

→ In order to limit a short-ckt current to a value which a circuit breaker can handle, additional reactance are connected in series, with the

the system at a suitable points is called reactors.

→ A reactor is a coil with no. of turns design to have a large inductance as compare to omit resistance.

→ The forces of turns of reactance under short-ckt condition are considerable and, therefore the winding must be solidly braced. It may be added that due to very small resistance of reactor, there is a very small change in the efficiency system.

Advantages:-

→ Reactors limit the flow of short-ckt current and thus protect the equipment from over heating as well as form failures due to the desructive mechanical forces.

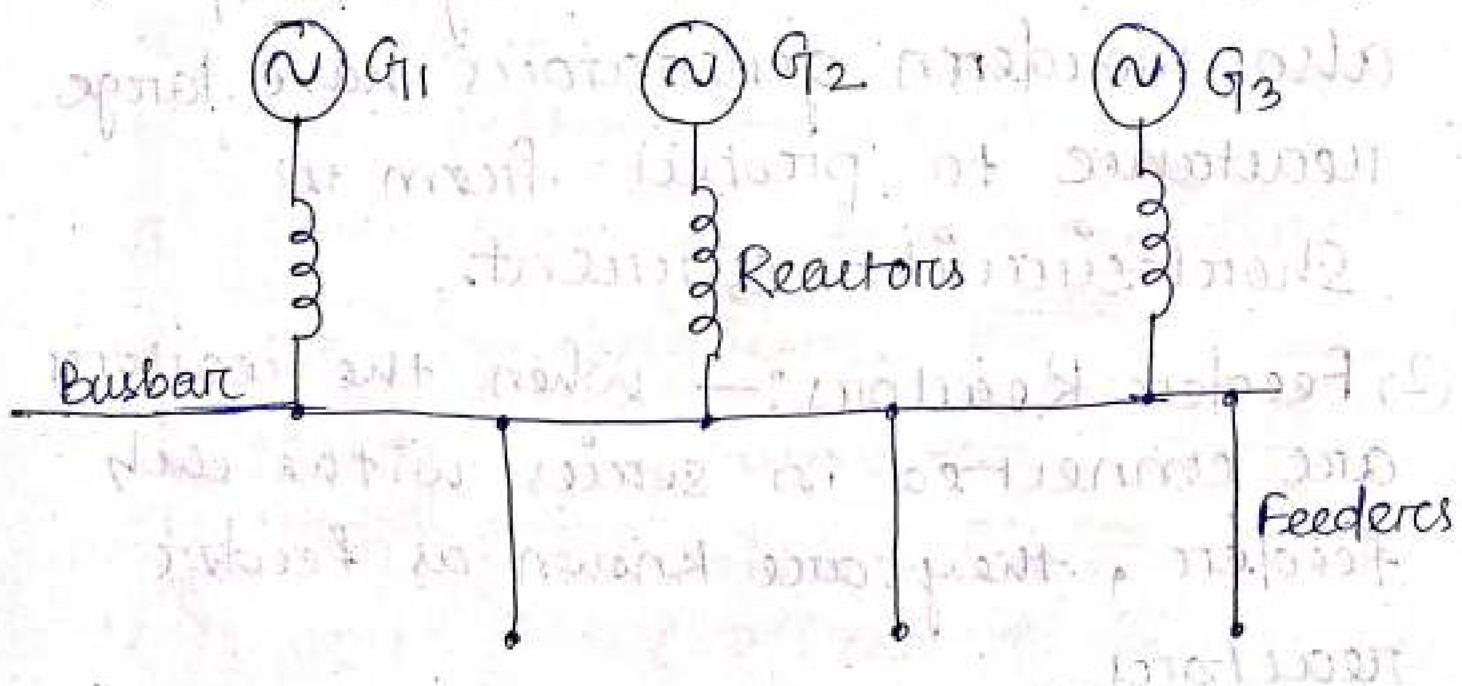
→ Troubles are localised and isolated at a point where they originate without communicating their disturbing effects ~~to those~~ to the other parts of ~~transformer~~ power system. This increases the continuity of supply.

→ They permit the installization of circuit breakers of lower rating.

(2.7) Location of reactors :—

→ Short circuit current limiting reactors may be connected (a) in series with each generator, (b) in series with each feeder, (c) in bus-bars.

(1) Generator Reactors :— When the reactor are connected in series with each generators, they are known as generator reactors.



Disadvantage :-

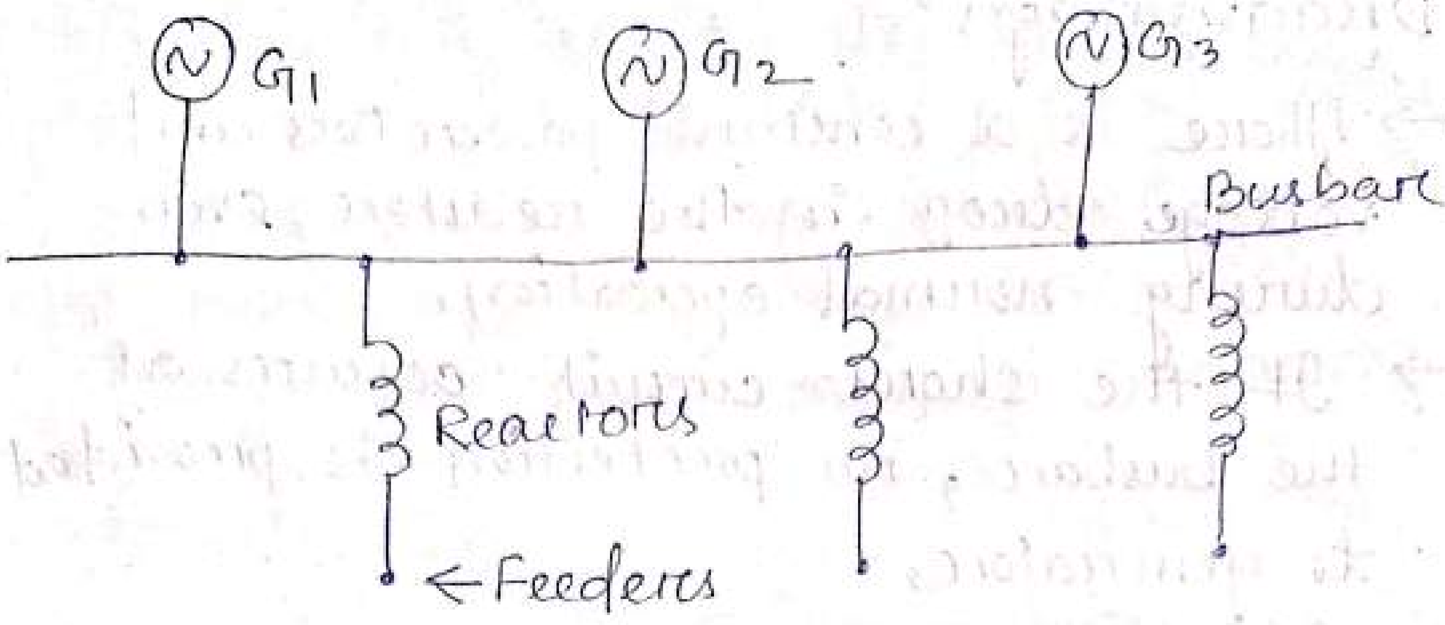
→ There is a constant voltage drop and power loss in the reactors even during normal operation.

→ If the bus-bar or feeder fault occure close to the busbar, and the voltage at the busbar reduced to a low value, thereby causing the generators to fall out of step.

→ If a fault occure on ~~may~~ any feeder, the continuity of supply to other is likely to be affected.

* Due to those disadvantages and also morderrn generators have large reactance to protect from ~~to~~ short circuit current.

(2) Feeder Reactors :- When the reactors are connected in series with the each feeder, they are known as feeder reactors.



→ Since most of the short circuits occurs on the feeders, a large no. of reactors are used for short circuits. Two principle advantages are claimed for feeder reactors.

→ Firstly, if a fault occurs in any feeder, the voltage drop in its reactor will not affect the busbar voltage, so that there is a little tendency for generator to lose synchronism.

→ Secondly, the fault on a feeder will not affect other feeders and consequently the effect of faults are localised.

Disadvantages:-

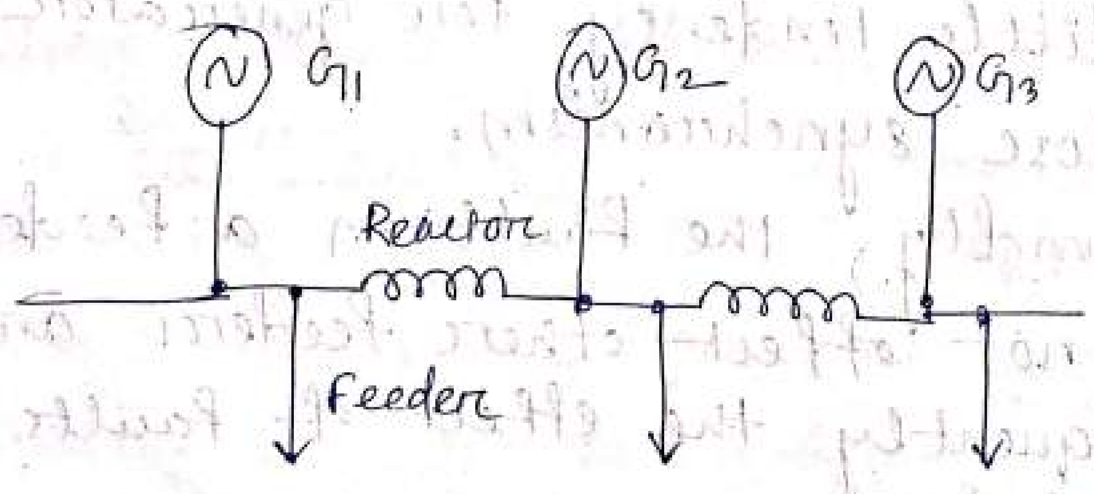
→ There is a constant power loss and voltage drop in the reactor even during normal operation.

→ If the short-circuit occures at the busbar, no protection is provided to generator.

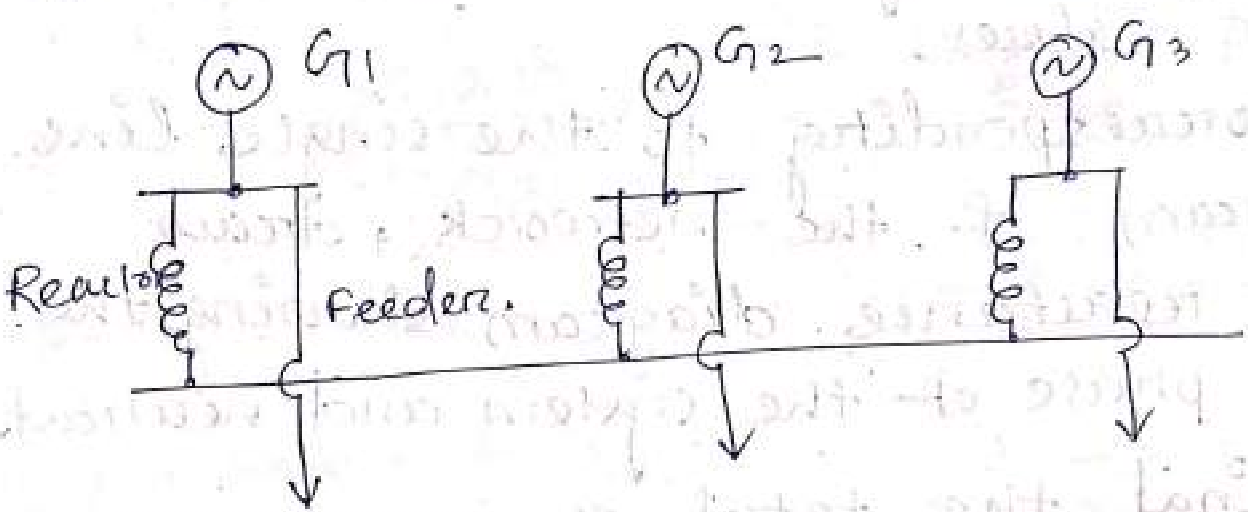
→ If the number of generator is increased, the size of the feeder reactor will have to be increased to keep the short-circuit current within the rating of feeder ckt breaker.

(b) → It is two types of :-

(i) Ring system :- In this sections busbar will divided into sections and these sections are connected through reactors.



(ii) Tie-bar System:— In tie-bar system there are effectively two reactors in series between sections, so that reactors must have approximately half the reactance of those used in comparable ring system.



2.8 Steps of symmetrical fault calcutions.

→ It has already been discussed that 3-phase short circuit faults results in symmetrical fault currents i.e fault currents in 3 phases are equal in magnitude but displaced 120° electrical from one another.

(i) Draw the single line diagram of complete network indicating the rating voltage and percentage of reactance of each element of network.

(ii) Choose a numerical ~~convine~~ convenient value of base KVA and convert all percentage reactances to this base values.

(iii) Corresponding to the single line diagram of the network, draw the reactance diagram showing the one phase of the system and neutral.

(iv) Final the total % reactance of the network upto the point of fault.

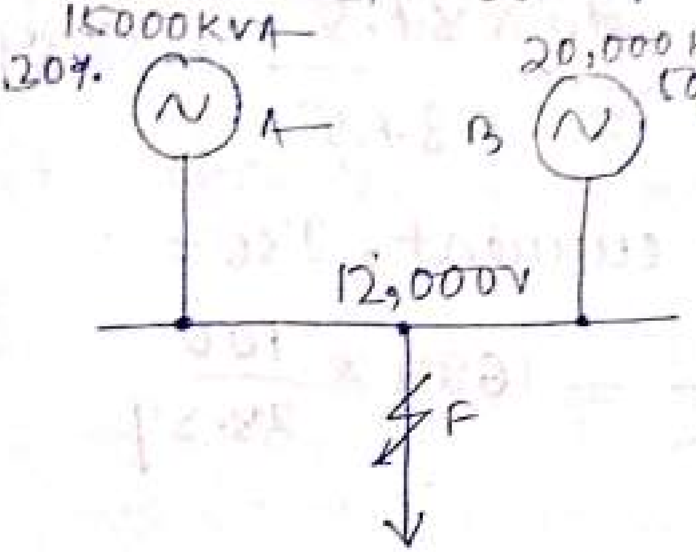
(v) Find the full load current corresponding to the selected base kVA and the normal system voltage at the fault point.

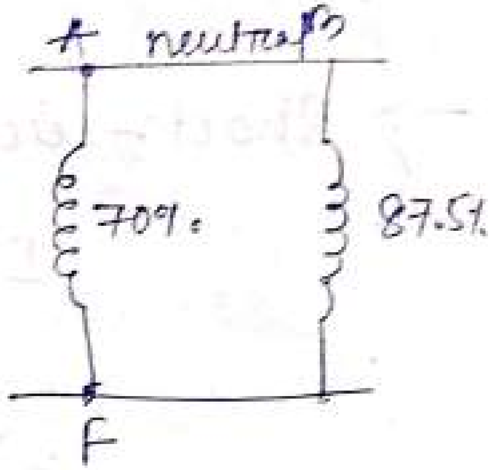
(vi) The various calculations are, $I_{sc} = I \times \frac{100}{\% x}$

$$\text{Short-ckt KVA} = \text{Base KVA} \times \frac{100}{\% x}$$

29 Example- 17.1

Find the short-circuit current that will flow into a complete 3-phase short-circuit at F.





Sol,

Let the base KVA is 35000 KVA,

then,

$$\% x \text{ of alternator A} = \frac{35000}{15000} \times 30$$

$$= 70\%$$

$$\% x \text{ of alternator B} = \frac{35000}{20,000} \times 50$$

$$= 87.5\%$$

→ Line current corresponding to 35000 KVA at 12KV is,

$$I = \frac{35000 \times 10^3}{\sqrt{3} \times 12 \times 10^3} = 1684 \text{ A}$$

→ Total reactance (%X) = $x_A \parallel x_B$

$$= \frac{x_A \times x_B}{x_A + x_B}$$

$$= \frac{70 \times 87.5}{70 + 87.5} = 38.89\%.$$

→ Short-circuit current, I_{sc} =

$$I \times \frac{100}{\%X} = 1684 \times \frac{100}{38.89}$$

$$\Rightarrow 4330 A.$$

Example - 17.2

A - 3ϕ, 20 MVA, 10 KVA alternator has internal resistance of 5% and neglagible resistance. Find the external resistance per phase to be connected in series with the alternator?

Solution :-

Full load current, $I = \frac{20 \times 10^6}{\sqrt{3} \times 10 \times 10^3}$

$= 1154.7 A$

Voltage per phase, $V = \frac{10 \times 10^3}{\sqrt{3}} = \frac{10000}{\sqrt{3}} V.$

$\therefore$ % x Total required = $\frac{\text{Full load cu}}{\text{Sh. ckt cu.}} \times 100$

$= \frac{1}{8} \times 100 = 12.5\%$.

$\therefore$ External % x required = $12.5 - 5$

$= 7.5\%$.

Now the % reactance $= \frac{Ix}{V} \times 100$

$\Rightarrow 7.5 = \frac{1154.7x}{\frac{10 \times 10^3}{\sqrt{3}}} \times 100$

$\Rightarrow x = \frac{7.5 \times 10000}{\sqrt{3} \times 100 \times 1154.7} = 0.375\,\Omega$