Date
22-10-2020

UNIT - III

Introduction to Substations

* The Substation may be defined as an assembly of apparatus installed to perform switching, voltage transformation, power-factor correction, power & frequency-converting operations.
* The purpose of a substation is to take power at high voltages from the T/m or sub T/m level, reduce its voltage & supply it to a no. of primary voltage feeders for distribution in the area surrounding it.
* In addition, it performs operational and emergency switching & protection duties at both the T/m & feeder level.
* It is also used as a local site for communication, storage of tools, etc.
* The sectional view of 33/11 kv substation is shown in fig {see S.S slide no. 5}

Factors Governing Selection of Site:

* voltage levels, voltage regulation, the cost of Sub t/m, substation, primary feeder mains & distribution T/F's dictate the location of a substation.
* However, the following rules are to be considered for the selection of an ideal location for a substation.
* The substation should be located nearer the load centre of its service areas, so that its distance from the substation is minimum.

* Proper voltage regulation should be possible without taking extensive measures.
* There should be proper access for incoming sub-T/m lines & out going primary feeders.
* It should provide enough space for future expansion.
* It should help minimize the no. of customers affected by any service interruption.

Classification of Substations

→ Substations are classified based on the service and locations i.e;

i) According to Service

ii) According to Location

According to Service:

* Based on service, the substations are classified according to voltage levels, switching operations, power-factor correction, change in frequency & conversion of AC to DC as follows

They are
i) Transformer Substation
ii) Industrial "
iii) Switching "
iv) Synchronous "
v) Frequency Change Substation
vi) Converting Substation.

Transformer Substation

These substations transform power from one voltage to another as per requirement.

They are

i) Transmission or primary Substations

ii) Sub Tlm or Secondary " "

iii) Step down or Distribution " "

i) Tlm or primary Substations:

⇒ These substations receive power from local generating stations (11kv or 33kv) and step up the voltage (220kv or 400kv) for primary Tlm so that huge amounts of power can be transmitted over long distances to the load centres economically.

ii) Sub Tlm or Secondary Substations

⇒ These substations receive the power from primary Tlm substations at high voltages (above 132 kv) and step down the voltage to 33 kv or 11 kv for secondary Tlm or primary distribution.

iii) Step down or Distribution Substations:

⇒ These substations receive the power from sub-Tlm substations or directly from power substations & step down the voltage for secondary distribution i.e; 400v for 3-ϕ or 230 V for 1-ϕ for household consumers.

Industrial Substations:

Some industrial consumers require huge amounts of power, it is advisable for such consumers to install individual substations. These substations are called industrial substations.

Switching Substations:

These substations are used for switching operations of power lines without the transformation of voltage. In this substation, different connections are made b/w different T/m lines.

Synchronous Substations:

At these substations, synchronous phase modifiers are installed for the improvement of the power factor of the system.

Frequency Change Substations:

These substations are used for converting normal frequency to other useful frequency and are supplied to industries which require high or low frequency.

Converting Substations:

These substations are used for converting AC into DC. This is useful for special purposes such as electric traction, electric welding, battery charging etc.

Classification of Substations -

According To Design :

* The main component of substation equipment are insulators, bus bars, circuit breakers, transformers, switches, relays etc., which are properly protected for continuity & quality of supply.
* According to design, the substations are classified as Indoor & outdoor substations.

Indoor Substations :

* Indoor substations are those whose apparatus are installed with in a building
* These substations are generally used up to 11 kV voltage only.
* Generally these types of substations are installed where the atmosphere is contaminated with impurities such as metal-corroding gases and fumes, conductive dust etc.

Outdoor Substations :

* Outdoor substations are classified as follows.
* They are
  i) pole Mounted Substation &
  ii) Foundation Mounted Substations

Pole Mounted Substations :

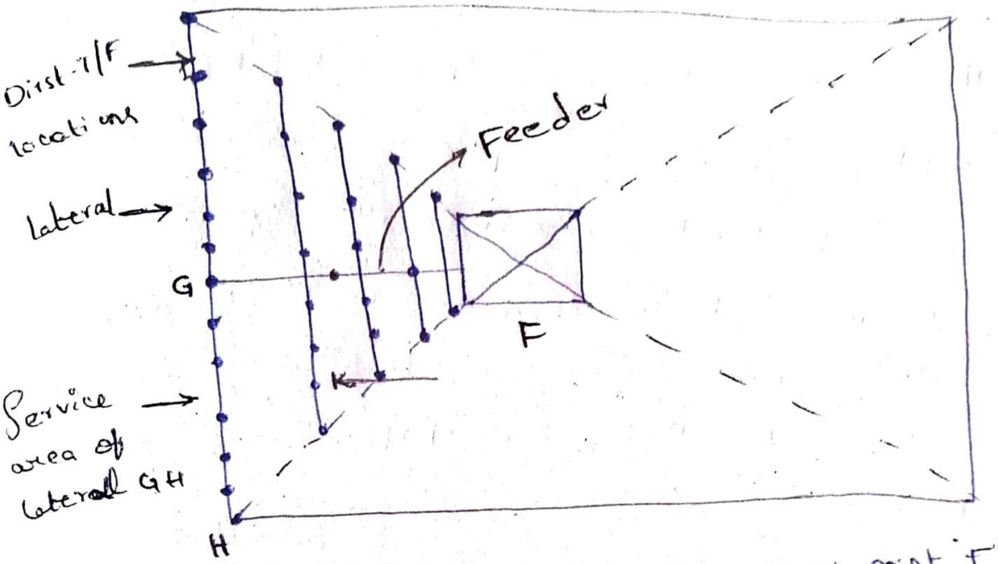
These are used for distribution purposes only and are usually mounted on double or four-pole structures with suitable platforms.

Foundation Mounted Substations:

* These are also called plinth mounted substations
* These are used for high rating transformers
* These are used due to the heavy weight of the transformer

Rating of Substations:

* Rating of distribution substation depends upon the load density of the service area.
* With increase in the load density, the additional load requirement can be met by
  i) Either the service area of given distribution substation remains same & increase the rating of the T/F.
  ii) Installing new distribution substation & thereby maintaining the capacity of the distribution substation T/F as constant.
* It is helpful to consider that the system changes for
  i) Short term distribution planning where the load density is constant.
  ii) Long term distribution planning where the load density is increasing.
* It simplifies greatly to analyze a square shaped service area representing a part of or entire service area of distribution substation
* Consider a square shaped service area served by four primary feeders from a central feed point in which each feeder & its subfeeders are of 3-ϕ ckt.



* The % of voltage drop from the feed point 'F' to the end of feed point 'H' is given by

$\% VD_{FH} = \% VD_{FG} + \% VD_{GH}$

* From the figure, each feeder supplies a load of

$S_4 = A_4 D$ (kVA)

→ where A_4 is the area supplied by one of four feeders emerging from load centre 'F' in square km.

→ D is the load density in kVA / square km.

the eq can be modified as

For square shaped area

$S_4 = L_4^2 D$ (kVA) $\{ \because A_4 = L_4^2 \}$

For uniformly distributed load the % voltage drop in the main feeder is given by

$\% V_{d4} = \frac{2}{3} L_4 C S_4$

where $C = \% V_d$ / kVA - km, depends on source voltages and conductor sizes

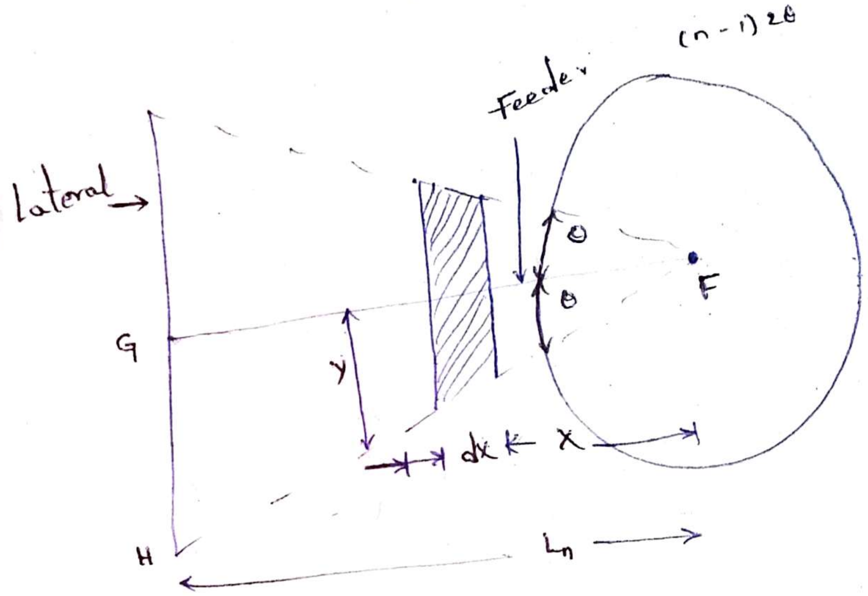
Sub S_4 in $\% V_{d4}$

$V_{d4} = \frac{2}{3} L_4^3 C D$

From the above eq it can be concluded that the total load is located at a point on the main feeder at a distance of $\frac{2}{3} L_4$ from the feed point 'F'.

Substation Service area with 'n' primary feeders

* The service area of the distribution substation is supplied by 'n' no. of primary feeders emerging from feed point 'F' as shown in figure.
* Consider that the load is uniformly distributed in the supplied area & each feeder supplies an area of triangular shape.



The differential load supplied by the feeder in a differential area of dA is

$$dS = D\,dA$$

where dA = differential area of the feeder, km2

from fig $y = (x + \Delta x)\tan\theta$

$\simeq x \tan\theta$

∴ The total supplied area of the feeder ckt can be determined as

$$A_n = \int_{x=0}^{L_n} \Delta A\, L_n^2 \tan\theta$$

and total load supplied by one of the 'n' feeders can be determined as $S_n = \int_{x=0}^{L_n} \Delta S = D L_n^2 \tan\theta$

This total load is located on the feeder ckt at $\frac{2}{3} L_n$ distances from the feed point 'F'.

∴ Addition of the % voltage drop contributions of all such areas is given by

$$\% V_{dn} = \frac{2}{3} L_n C S_n$$

Sub S_n

$$\therefore \% V_d = \frac{2}{3} L_n^3 D C \tan\theta$$

From the fig. $n(2\theta) = 360$; $\theta = \frac{360}{2n}$

The eq. can be modified as

$$\% V_{dn} = \frac{2}{3} L_n^3 C D \tan\left(\frac{360}{2n}\right)$$

The eq. is suitable if no. of feeders 'n' ≠ 13.

If no. of feeders is one (i.e; n = 1)

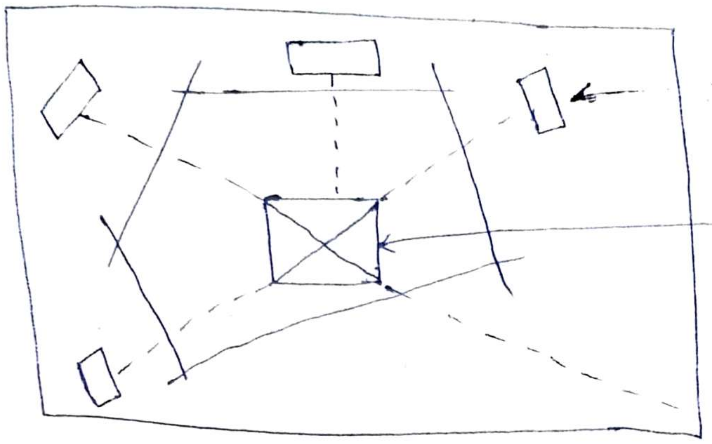
$$V_{d_1} = \frac{1}{2} C D L_1^3$$

If $n = 2$

$$\% V_{d_2} = \frac{1}{2} C D L_2^3.$$

Optimal Location of Substations:

* Every consumer in a utility system should be supplied from the nearest substation.
* Supplying each consumer from the nearest substation assumes that the distribution delivery distance is as short as possible which inturn reduces the feeder cost, cost of electrical power loss & service interruption exposure.
* Substation must be located as close as possible to the consumer.
* perpendicular bisector rule.
* It is simple graphical method of applying the concept "Serve every consumer from the nearest substation" to a map in order to determine the "optimum" substation service areas & their peak loads.



* Draw a st. line b/w a proposed substation and each of its neighbours.
* perpendicularly bisect each of those lines i.e; divide it in two with a line that intersects it at an angle of 90°.
* Set of all ⊥lar bisectors around a substation defines its service territory.
* Target load for this substation will be sum of all loads in its service territory.

* X - Y Coordinate method.
* Total KVA load fed through a particular node is TKVA (i) for i = 1, 2, 3 ... no. of nodes (nn)
* TKVA is always available from the load computation.
* Optimum location of substation is computed through an iterative algorithm.
* By minimizing the real power loss, the optimal location of substation (X(S), Y(S)) for substation 'S' can be computed through the following expression

$$X(s) = \frac{\sum_{i=2}^{nn} W(i)\, X(i)}{\sum_{i=2}^{nn} W(i)}$$

$$Y(s) = \frac{\sum_{i=2}^{n} W(i)\, X(i)}{\sum_{i=2}^{n} W(i)}$$

Where $X(i)$ & $Y(i)$ = x and y coordinates of the consumer load point for $i = 1, 2, 3, \ldots n$.

$W(i)$ = Real load at node i.

Merits of Outdoor Substation:

* Outdoor substations have the following merits over indoor substation.
* All the equipment is visible. So the identification of fault is easier.
* Expansion of the substation is easier.
* Takes less erection time.
* There is no necessity of building. So it requires less building material.
* The construction work required is comparatively smaller and hence, the cost of the switchgear installation is low.
* The spacing b/w the apparatus is more, so less damage occurs due to faults.

Demerits of Outdoor Substation

⇒ Switching operations, the supervision & maintenance of apparatus are to be performed in the open air during all kinds of weather.

⇒ Requires more space for arranging apparatus in the substation.

⇒ The apparatus is exposed to the sun. It requires special design, therefore, for withstanding high temperatures.

⇒ The apparatus requires more maintenance due to dust & dirt deposition on the outdoor substation equipment.

⇒ These are prone to lightning strokes

Substation Equipment:

* The various equipments required in a substation depend upon the type of substation, service requirement and protection impoltance.
* However, the following main equipments are generally used in most of the substations.

Substation Equipment:

The main Components in a substation are

→ Busbar
→ Insulators
→ Isolators
→ Transformers
→ Indicating & metering Instruments
→ protective Relays
→ Lightning Arrester.

Bus Bars:

* A bus bar term is used for a conductor carrying current to which many connections are made.
* These are generally used in substations where the no. of incoming Lines & outgoing lines takes place at the same voltage.
* Bus bars used in substations are of Copper & aluminium & they are bare rectangular cross section bars or round solid bus bars, but the former is more commonly used since it is more economical as compared to the latter.
* According to the type of the construction of the bus bar, it can be classified into 2 kinds.
* These are:

i) Copper or copper clad steel tubes or aluminium tubes supported on post insulators.

ii) Standard copper or ACSR wires or cellular hollow wires strung b/w strain insulators. They are 5-6 m in length.

Insulators:

* porcelain insulators are used in substations to support & insulate the live conductors & bus bars.

Isolators:

* Isolators are used for isolating the ckt when the current has been already interrupted.
* Isolators are used only for connecting & disconnecting parts of electrical installations after de-energizing them by opening their ckt's with the respective ckt breakers.

Transformers:

* A transformer is a static device used to transform power from one voltage level to another voltage level without changing the frequency.

Indicating & Metering Instruments:

* Ammeters, voltmeters, PF meters, watt meters, energy meters, KVAr meters are installed in substation for control & measurement purposes. In case of all substations (including 33kv/11kv substations), it is necessary to provide recording voltmeters.

Protective Relays:

* These are installed for the protection of equipment against faults or overloads.

Lightning Arresters

* All the equipment in the out door substations should be protected against direct lightning strokes and travelling waves reaching the station over the T/m lines.
* By shielding the station equipment, equipment can be protected against the direct strokes.

Bus Bar Arrangements

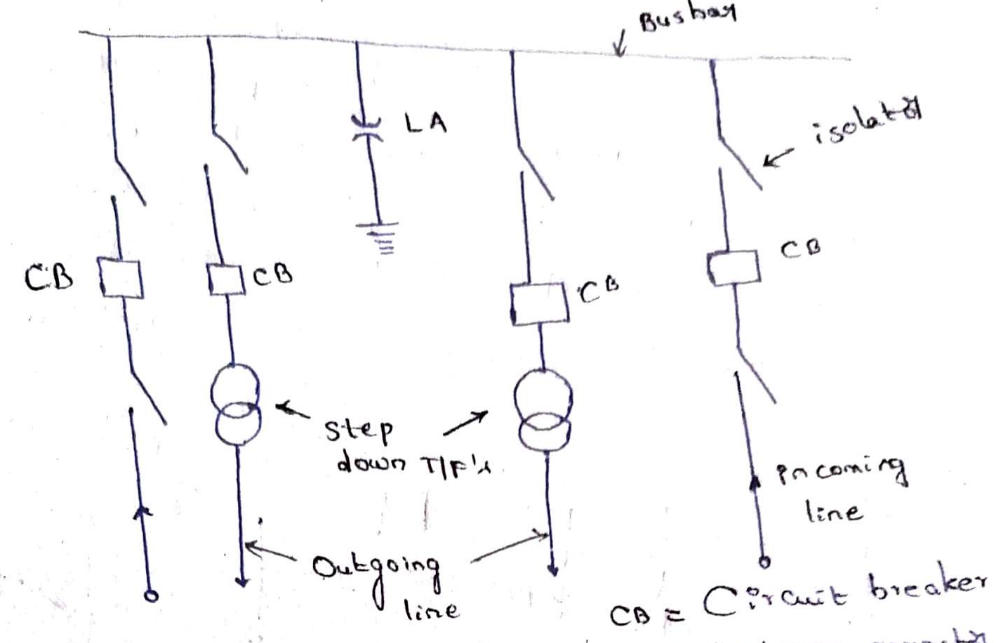
The different types of busbar arrangements are

1. Single bus bar
2. Single bus bar s/m with sectionalization
3. Double bus bar with single breaker
4. Double bus bar with two ckt breakers
5. Breakers & a half with two main buses
6. Main & transfer bus bar
7. Double bus bar with bypass isolator
8. Ring bus

Single Bus Bar Arrangement

* It consists of a single bus bar & all the incoming and outgoing lines are connected to the same bus bar.
* Here, the 11kV incoming lines are connected to the bus bar through isolators & ckt breakers
* 3-ϕ, 400V, & 1-ϕ, 230V outgoing lines are connected through isolator, ckt breaker, and step down T/F from the bus bar.
* This type of arrangement is suitable for DC stations and small AC stations
* The major drawback of this s/m is that, if the fault occurs on any section of the bus bar, the entire bus bar is to be de-energised for carrying out the repair work.

* So, this results in a loss of continuity of service of all feeders



CB = Circuit breaker
LA = Lighting arrestor

Merits

⇒ Each of the outgoing ckts requires a single-ckt breaker. So, this type of arrangement is the cheapest one.

⇒ The relaying s/m is simple

⇒ The maintenance cost is low.

⇒ The bus bar potential can be used for the line relays

Demerits

⇒ Maintenance without interruption of supply is not possible.

⇒ Expansion of the substation without shut-down is not possible.

Single bus bar with Sectionalizer Arrangement

* The sectionalization of the bus bar ensures continuity of supply on the other feeders, during the time of maintenance or repair of one side of the bus bar.

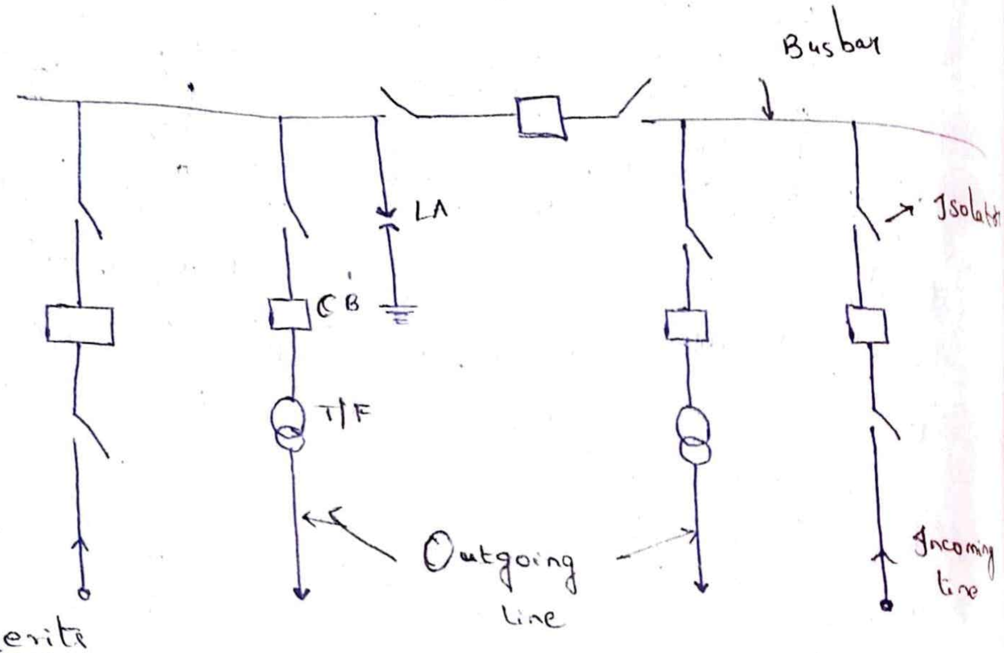
* The whole of the supply need not to be shut down

* The no. of sections of a bus bar is usually 2 or 3 is a substation but actually it is limited by the short ckt current to be handled.

* Another advantage of sectionalization is that the

Ckt breakers of low breaking capacity can be used on the sections as compared to the previous case.

* In case of duplicate feeders, they are connected to different sections of the bus bars so that in the event of a fault on one of the bus bar sections, the feeders connected to it are immediately transferred to the healthy bus bar section & the faulty section is isolated.



Merits

* The operation of this s/m is simple as in case of the single bus bar.
* The maintenance cost of this s/m is comparable with the single bus bar.
* For maintenance or repair of the bus bar, only one half of the bus bar is required to be de-energized. So complete shut down of the bus bar is avoided.
* It is possible to utilize the bus bar potential for line relays.

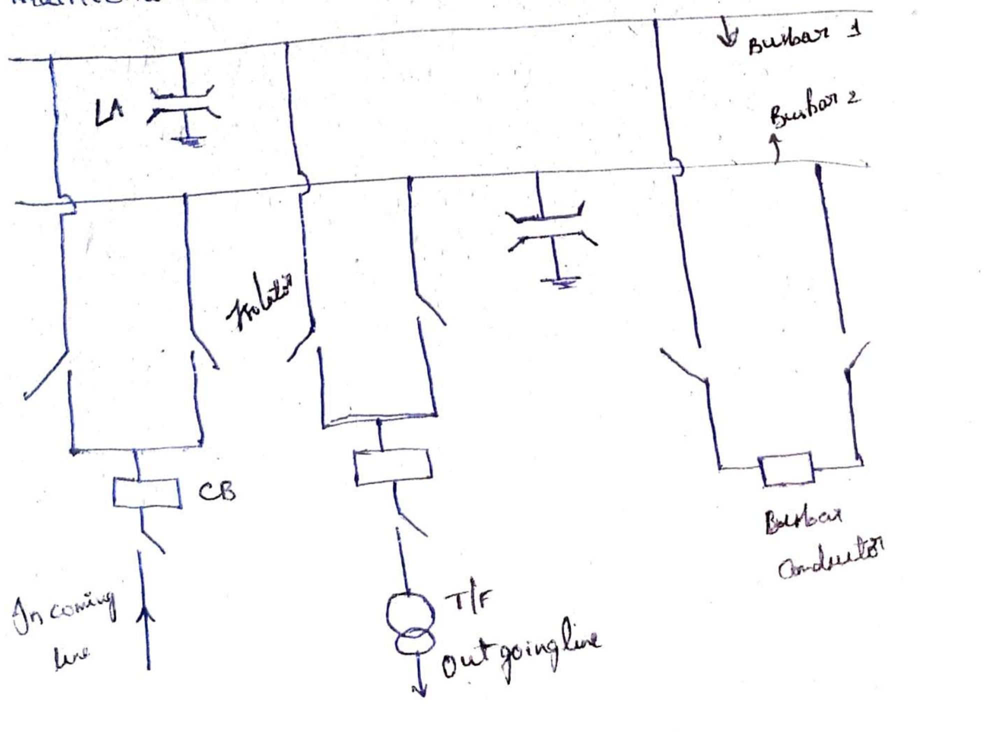
Demerits:

* In case of a fault on the bus bar, one half of the section will be switched off.
* For regular maintenance also, one of the bus bars is required to be de-energized.

* For maintaining or repairing a ckt breaker, it is required to be isolated from the bus bar.

<u>Double Bus bar With Single ckt breaker Arrangement</u>

* It Consists of two identical bus bars, one is the main bus bar & another one is spare bus bar.
* Each bus bar has the capacity to take up the entire substation load.
* Each load may be fed from either bus bar.
* The load ckts can be further divided into two separate groups based on operational considerations (maintenance or repair).
* Any bus bar may be taken out for maintenance and cleaning of insulators.
* With the help of bus coupler, the incoming & or outgoing lines are connected to any bus bar through isolator & ckt breaker.
* This s/m is adopted when the voltage is greater than 33kv.
* This arrangement does not permit breaker maintenance without causing interruption in supply.



Merits :

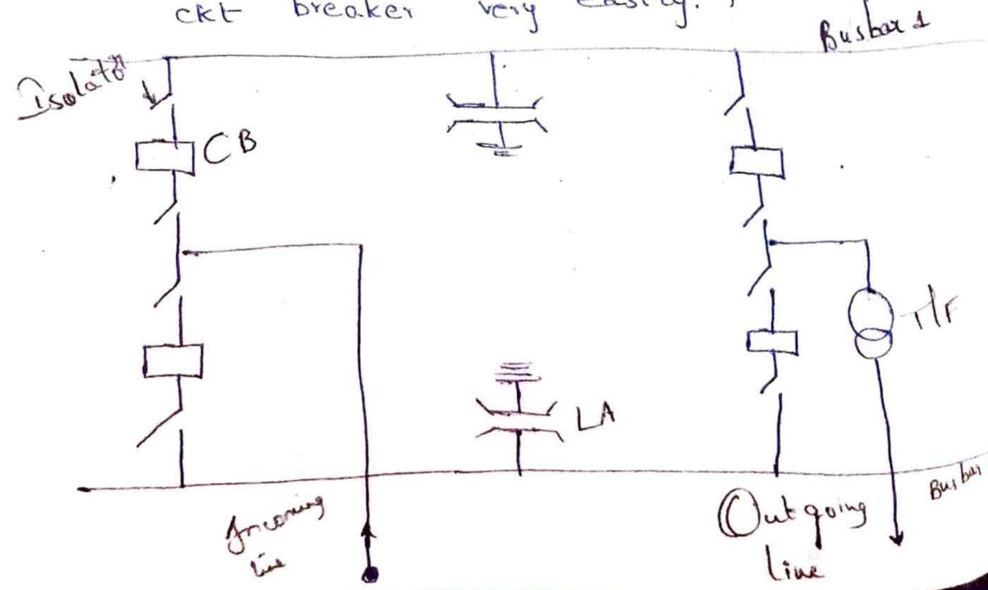
* Permits some flexibility with two operating buses
* Any main bus may be isolated for maintenance.
* The ckt can be transferred readily from one bus to another by using bus-coupler & bus-selector disconnect switches.

Demerits

* One extra breaker is required for the bus coupler
* Three switches are required per ckt.
* High exposure to bus faults.
* If bus coupler fails, the entire substation runs out of service.

Double bus bar with two ckt breakers arrangement.

* This is a simple & flexible arrangement
* It is expensive & ~~hence relay~~ hence is rarely used.
* It is used in large generating substations which require a high security connection.
* It provides the best maintenance facilities for maintenance to be carried out of on the ckt breakers.
* Thus, when one ckt breaker is opened for maintenance of repair works, the load can be transferred on to the other ckt breaker very easily.



Merits :

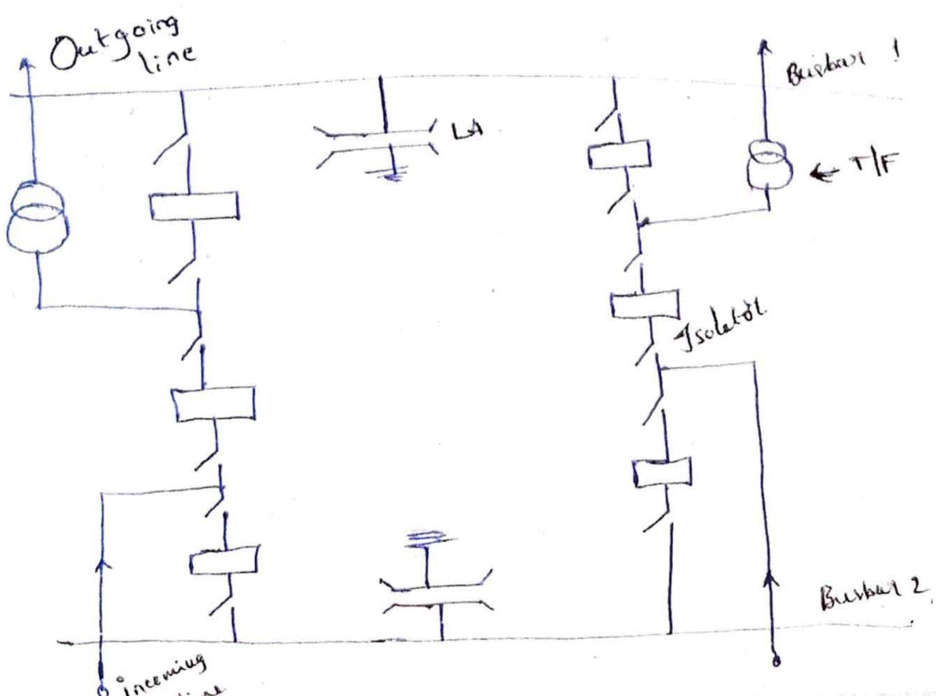
* Two ckt breakers in each ckt.
* Has flexibility to connect the feeder ckts to any bus
* For service maintenance any breaker can be taken out
* High reliability.

Demerits :

* More expensive.
* If ckts are not connected to both buses, the bus bar loses half the ckt for breaker failure & interprete supplies.

Breaker and a half with two main buses arrangement

* This method is an improved version of double bus bar with two ckt breakers and uses Lesser no. of ckt breakers.
* In this method, one spare breaker is provided for every two ckts.
* When the breaker (own) is taken out for maintenance, the protection is complicated since it must associate the central breaker with the feeder.



Merits :

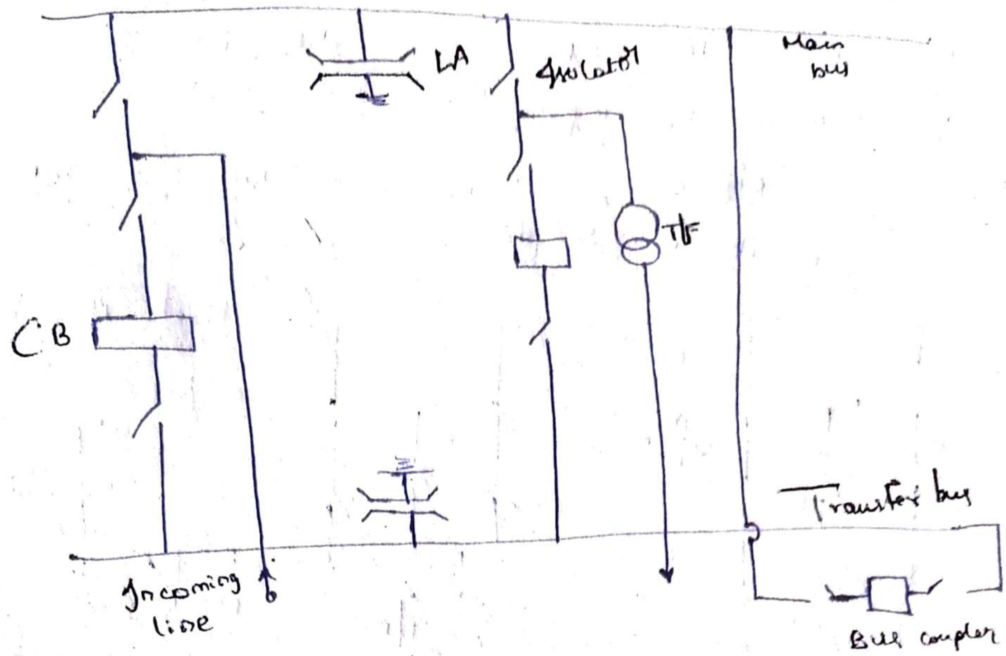
* This s/m is more economical as compared to a double-bus double breaker arrangement
* A fault in a breaker or in a bus will not interrupt the supply.
* Addition of ckts to the s/m is possible.
* High reliability.
* Any main bus can be taken out of service at any time for maintenance.

Demerits :

* 1½ breaker per ckt.
* The relaying becomes more complicated as compared to that in a single bus arrangement

Main and Transfer Bus bar

* This arrangement is an alternative to the double bus bar scheme.
* In this arrangement any line ckt breaker can be taken out for maintenance & repair without affecting the supply.
* This is done by closed transfer ckt breaker and changing the load to transfer bus bar and then removing the line breaker from service.
* Only one breaker at a time can be removed from service and the transfer breaker takes its place when it is out of Service.
* In a substation, to work on a bus bar, it is often necessary to remove it from Service.
* This is possible only by transferring the load to the other bus bar.



Merits

* It ensures supply in case of bus fault. In case of any fault in a bus, the ckt can be transferred to the T/F bus.
* It is easy to connect the ckt from any bus.
* The maintenance cost of substation decreases.
* The bus potential can be used for relays.

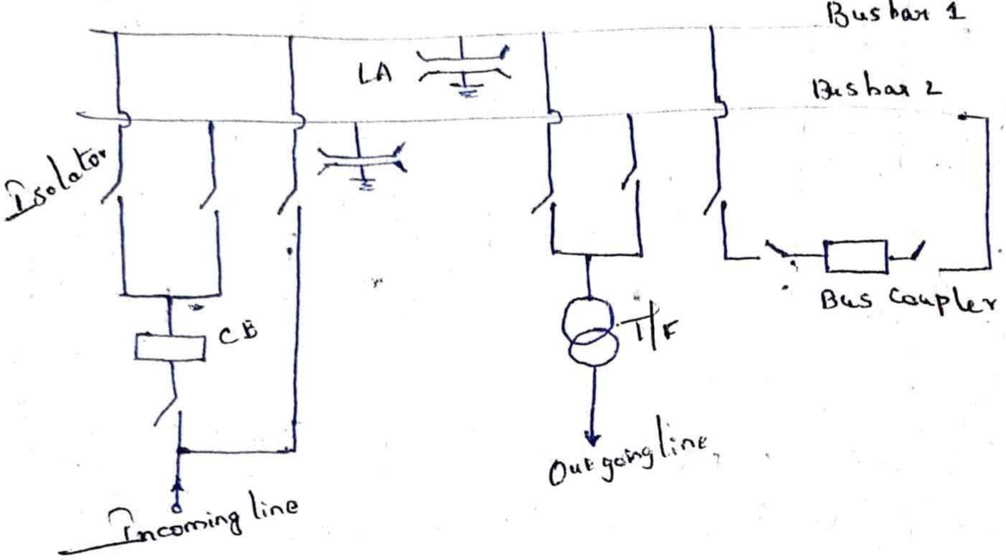
Demerits :

* Requires one extra breaker for the bus tie.
* Switching is somewhat complicated while maintaining a breaker.
* Failure of bus or any ckt breaker results in shut down of entire substation

Double Bus bar with bypass Isolator Arrangement

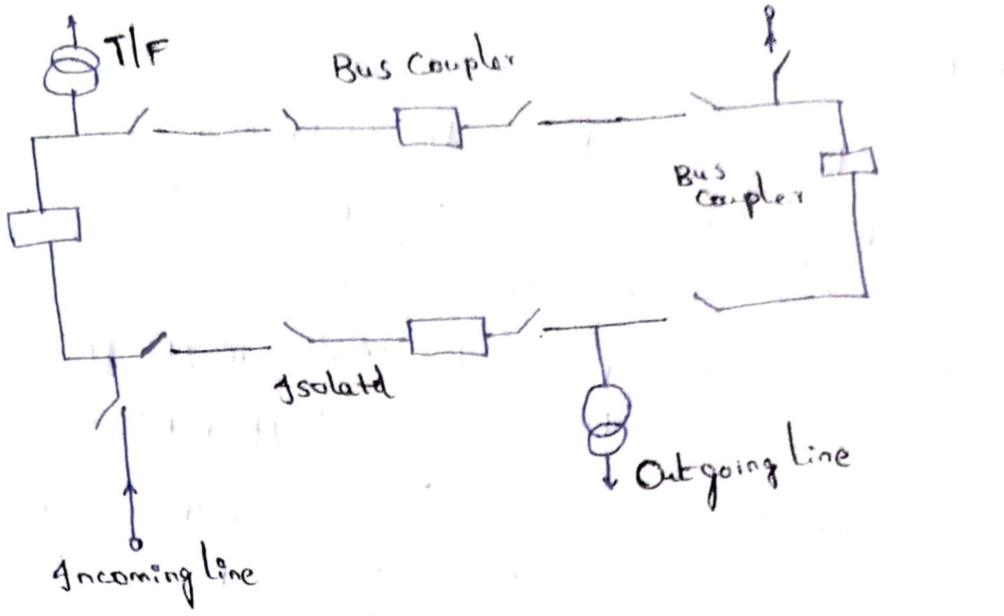
* This is a combination of a double-bus & main transfer bus scheme.
* Any of the bus bars can act as a main bus & another bus is used as the transfer bus.
* The advantage of this method is that any ckt breaker or any bus can be taken out for service without affecting the supply.

* In substations, it is frequently necessary to take bus bar & the ckt breaker out of service for maintenance & repair.
* So this scheme is the recommended one both because it is simple & economical.



Merits :
⇒ Simple in Construction
⇒ Cheaper in cost.

Ring Bus bar Arrangement :
* This is an extension of the sectionalized bus bar arrangement.
* By using two bus couplers, the end of the bus bars are returned upon themselves to form a ring.
* The sectionalizing and busbar Couplers are in series.
* There is a greater flexibility of operation.
⇒ Different types of ring & mesh buses utilized are
i) Simple ring
ii) Rectangular Ring
iii) Circulating Ring
iv) Zig zag ring.



Merits

* Low initial and ultimate cost.
* Flexible operation for breaker maintenance.
* Any breaker can be removed for maintenance without interrupting load.
* Required only one breaker per ckt.
* Does not use main bus.

Demerits :

* It is necessary to trip two circular breakers to isolate a faulted line, which makes the relaying quite complex.
* It is necessary to supply potential to relays separately to each of the ckts.
* It is difficult to add any new ckt to the ring.

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