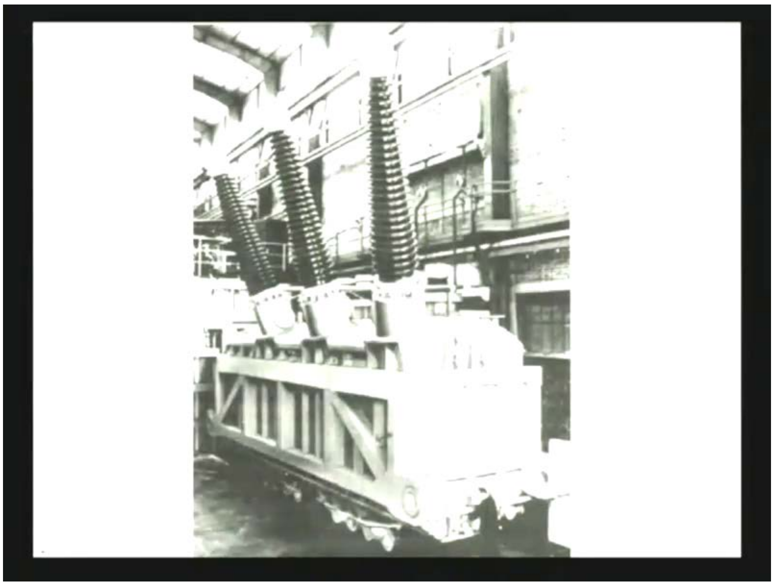
Electrical Machines - I
Prof. D. Kastha
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 11
Construction of Three Phase Transformers

(Refer Slide Time: 01:15)

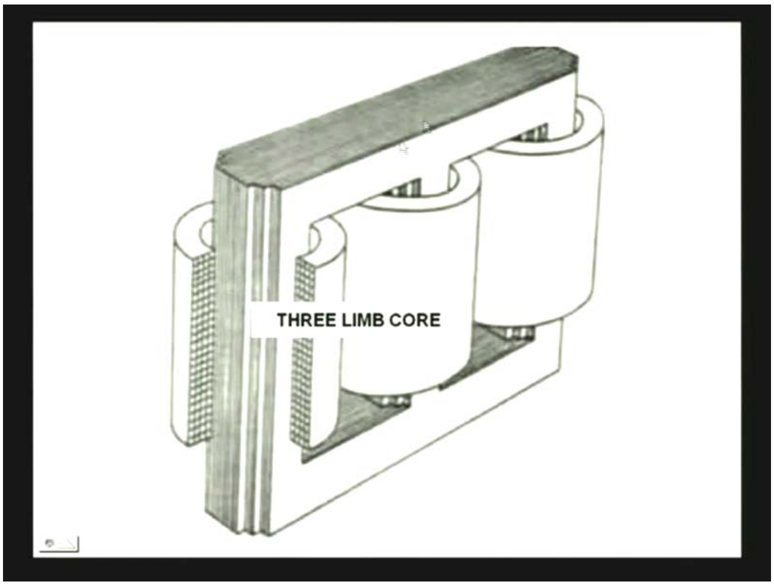


In the operating principle of three phase transformer and single phase transformer being similar, it is expected that the constructional features of the two transformers will also be similar. However, in appearance the three phase transformer looks significantly different, one is shown in this diagram. From outside it looks like a box or a tank seated with a large number of accessories. In this lecture, we will see how the main parts of the transformers are constructed their purpose and as well as the construction and purpose of this accessories.

(Refer Slide Time: 01:43)

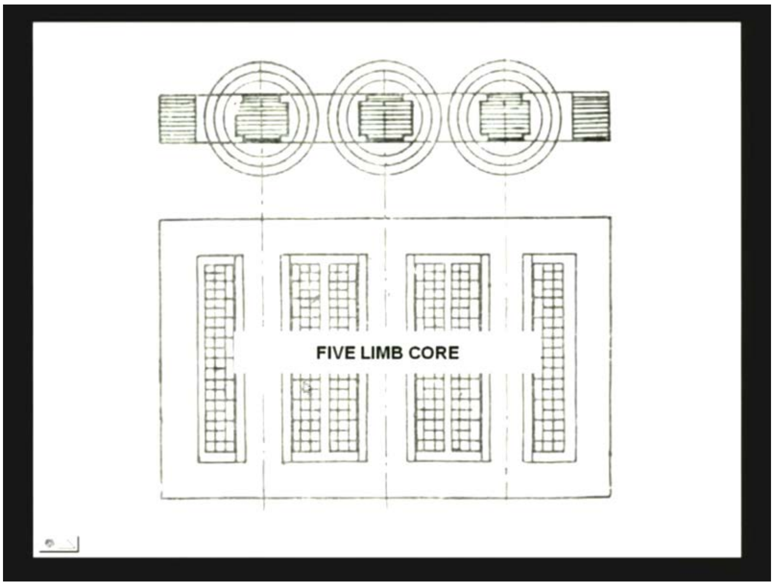
So, if we look at a cutout view of a transformer we find that inside the tank we find the core of the transformer, the windings, the terminals, and there is an overhead conservator like this.

(Refer Slide Time: 02:15)



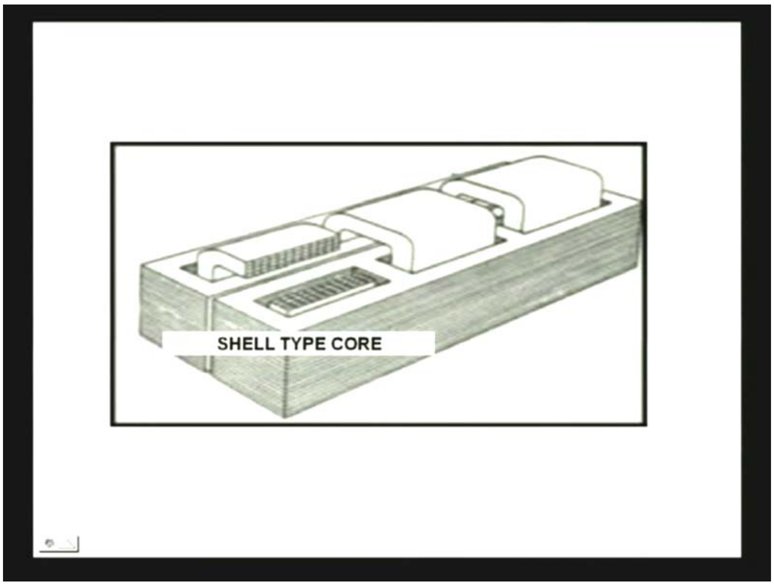
The essential part of the transformer consists of a core with windings on the limbs. In the last lecture we have seen that a three phase transformer built as a single unit can be made up of three limbs. The written limb for the flux is not necessary since the sum of the fluxes is 0; however, this three limb construction does offer slight imbalance to the flux path.

(Refer Slide Time: 02:49)



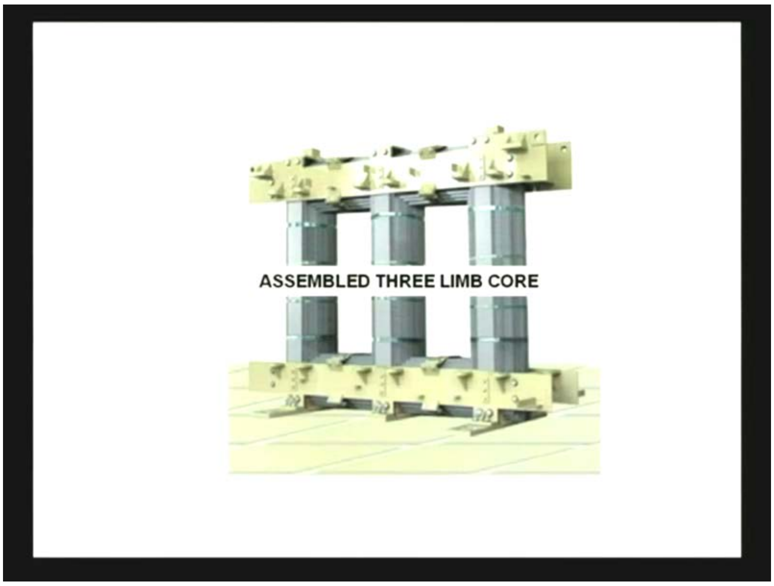
Therefore, for very large transformer a five limb construction is used where the windings are placed on the inner limbs; the two outer limbs do not carry any winding. This provides a more balanced magnetic path for the three phase flux and the windings the phases operate more or less independent of each other under balanced operating condition. There is another construction; incidentally, this construction and the next these are called core type transformer.

(Refer Slide Time: 03:30)



There is a different construction which is called the shell type transformer in which case the three phases operate on completely separate magnetic circuit, and they operate independently one of each other. However, for most three phase power transformer the three limb construction is the most common and that is what we will assume in our discussion.

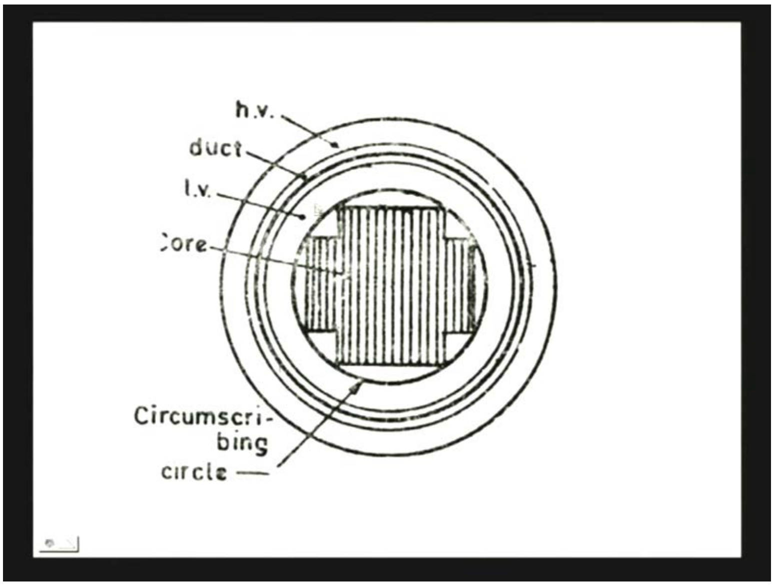
(Refer Slide Time: 04:04)



So, here is a look at the assembled three limb core. There are several parts to it. These vertical parts are called the core; the horizontal one is called the yolk. As in the case of a single phase transformer these are not solid iron bars; however, they are made up of thin steel lamination. The purpose of the core is similar to that of a single phase transformer that is to provide load reluctance path for the flux and as well as to support the winding and provide mechanical strength.

Since, the flux flows along this direction the transformers cores are laminated along this in this way. So, these cores are made up of long strips of thin steel plate, the material being either hot-rolled or cold-rolled grain oriented steel. For large transformer it is usually cold-rolled. Since, these are made up of steel laminations it is necessary to bolt them down with clamps; these are the clamping pieces of the core.

(Refer Slide Time: 06:00)

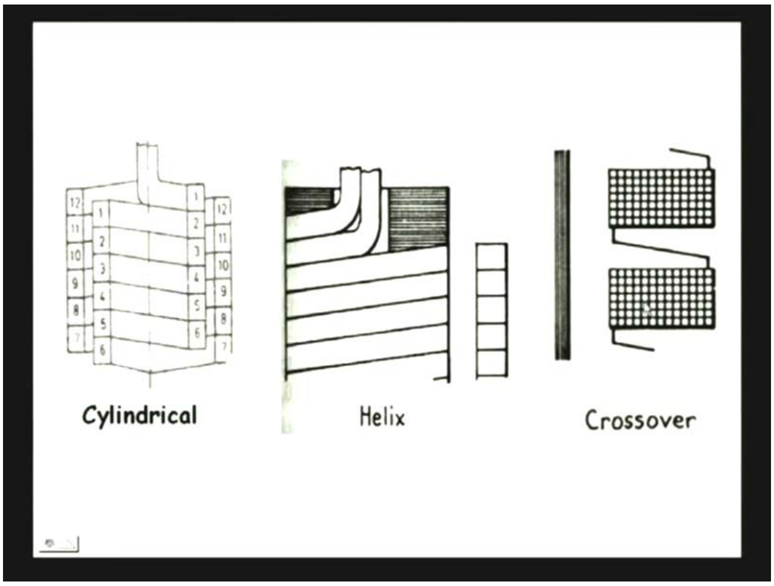


If I look at top view of one of the core along with the winding, it will look somewhat like this. This part is the actual core cross-section on which there is an insulating bobbin cylinder, this being made up of press bolt or SRBP cylinder. On the cylinder first the LV winding will be placed, then there will be a gap between the LV winding and the HV winding. There will be a second cylinder on which the HV winding will be placed, and there will be a gap between HV and LV winding through which cooling fluid may be circulated.

One interesting thing about the core structure is that it is not square; the reason is simple. In order to support certain amount of voltage and not to exceed the given flux density, the core cross section must have some minimum area, and it is well known that for a given area a circle has the minimum circumference. Since, the windings are placed around the core it is necessary, it is advantageous that this circumference is minimized, so that the length of the mean turn of both LV and HV winding can be minimized thereby minimizing the resistance and the losses.

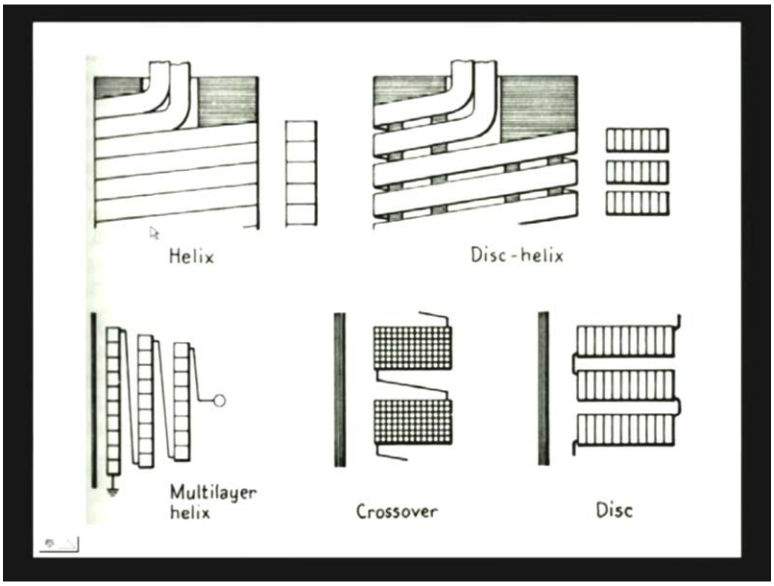
Therefore, it is necessary to accommodate the core of a given area with minimum circumference. Now ideally the core cross section should have been a circle, but cores are also needed to be laminated. If a very good approximation to this circle is made, then laminations of different continuously varying width will be necessary which is problematic from the point of view of production. Therefore, a compromise is arrived at; therefore, generally instead the cores are made in the step form. This is called a cruciform core with only two step, for larger transformer even larger number of step 5, 6 up to 6 is used, so that the circular space in this is more maximally utilized.

(Refer Slide Time: 08:56)



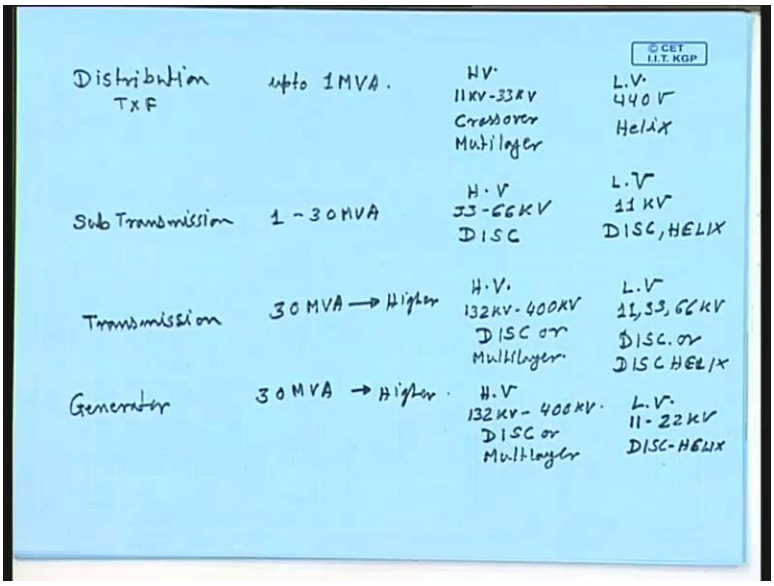
The next important thing in transformer construction is the windings. The purpose of the windings are to carry the magnetization current that produces flux and also transfer power from one winding to another. These windings are made up of solid or stranded copper or aluminum strips. There are different types of windings that are used. It depends on the power and the voltage rating of a particular winding. This figure shows some of the common winding configurations. The first one is cylindrical, then second one is called the helix, and the third one is called the crossover. These are normally used for low voltage winding; this is for high voltage winding with many turns.

(Refer Slide Time: 10:03)



Here we have a few more; this is the same helix, this is called a disc-helix. This is the disc where the windings are found in the concentric manner to form a winding disc. This is the crossover, and this is the multilayer helix. The same helix can be put on several layers of them to form this multilayer helix. Now depending on the application MVA rating and the KVA rating of the transformer in question different windings are used.

(Refer Slide Time: 10:48)

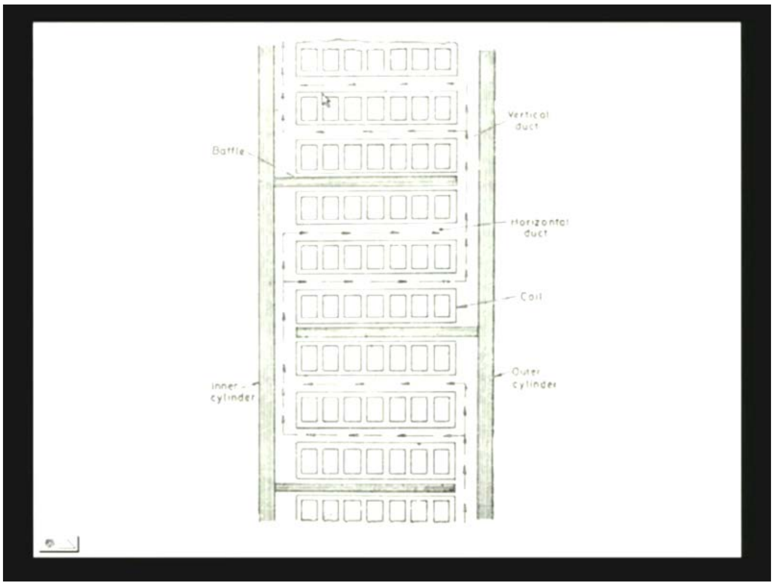


For example if it is a distribution transformer of MVA rating let us say up to 1 MVA, the HV voltage rating is 11 kV to 33 KV. Then the H winding will be normally it will be either crossover; this is the crossover, this is the crossover winding or this is the crossover winding or multilayer. Similarly, the LV winding for distribution transformer will usually be rated at 440 volt. The choice of winding for this is helix which is shown here.

This is the helix winding; this is on the lower spectrum. Let us see something at the medium spectrum which is the sub transmission level. This is let us, say, from 1 to 30 MVA; the HV voltage will be in the range of 33 to 66 KV. The preferred HV winding type for this is disc. This is the disc winding. The LV voltage for this type of transformer will usually be 11 KV, and for this LV winding usually disc or helix winding will be used. This is the disc winding, and this is the helix winding. Coming back going further higher up in the MVA rating transmission, it will be 30 MVA and upwards to higher.

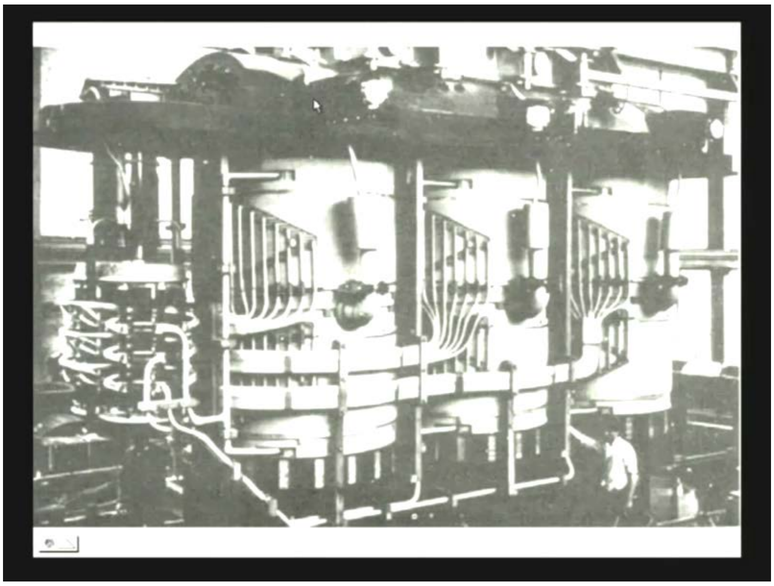
The HV voltage will be in the range of 132 KV to 400 KV. The preferred choice is disc or multilayer. The LV voltage can be 11 KV, 33 KV or 66 KV, and this is disc or disc helix. This is the multilayer helix, and this is the disc, and this is the disc helix. Coming to generator transformer, this is also 30 MVA or upwards, the HV side it is again 132 KV to 400 KV, and the choice is disc or multilayer. LV voltage, it is the voltage generated by the generator; it will be in the range of 11 to 22 KV, and the choice of winding is disc helix. So, this is a rule of thumb, but depending on the special application a particular type of winding is chosen.

(Refer Slide Time: 16:04)



Whatever may be the choice of the winding, it must be ensured that there is enough space around the conductors around different layers of conductors and between different levels, so that the cooling fluid usually oil or air can flow through it. So, this is the inner cylinder must have some gap; before the winding starts these are usually provided by spacers which are non-conducting material. And spacers are placed here also, so that there are ducts formed in between the windings and windings and the inner cylinder between winding and the outer cylinder and the layers of the windings. This is necessary in order for the cooling medium that is the cooling oil to flow in an uninterrupted manner, so that it can carry the heat generated where the I square are loss in the windings to the outside cooling medium.

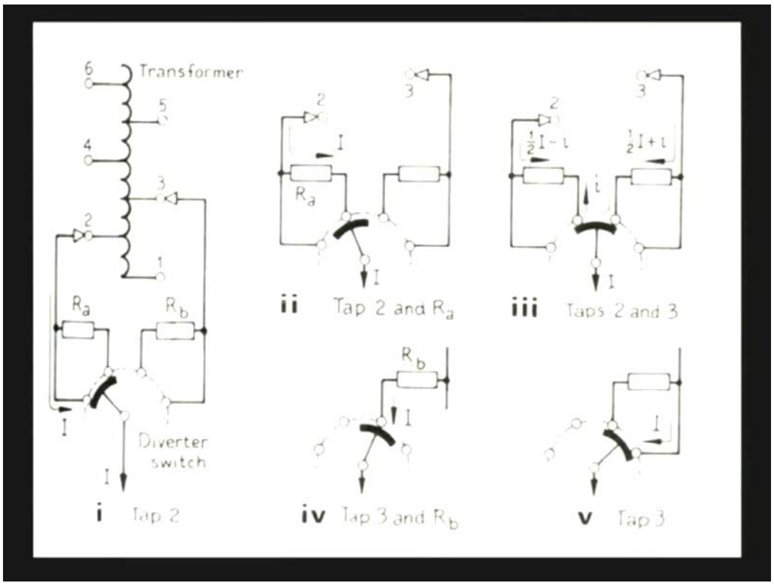
(Refer Slide Time: 17:26)



Another interesting feature of a three phase transformer which is normally not found on single phase transformer is the arrangement of tapping. Tapping is necessary so that the voltage on the HV or LV side can be controlled. The tapping is done by either inserting additional turns in a particular winding or removing some turns from a winding. Therefore, there will be a section of the winding usually on the high voltage side which will have several terminals coming out from them.

Here these terminals are in this picture on the three phases these terminals are shown, and there will be a selection switch which can choose the terminal at which the transformer external connection is connected at any point. There are two different ways these tap changing can be done. One is called the offload tap changing where during changing from one tap to another; there will be a momentary disconnection of supply, and on load tap changing where the supply will not be disturbed.

(Refer Slide Time: 18:57)

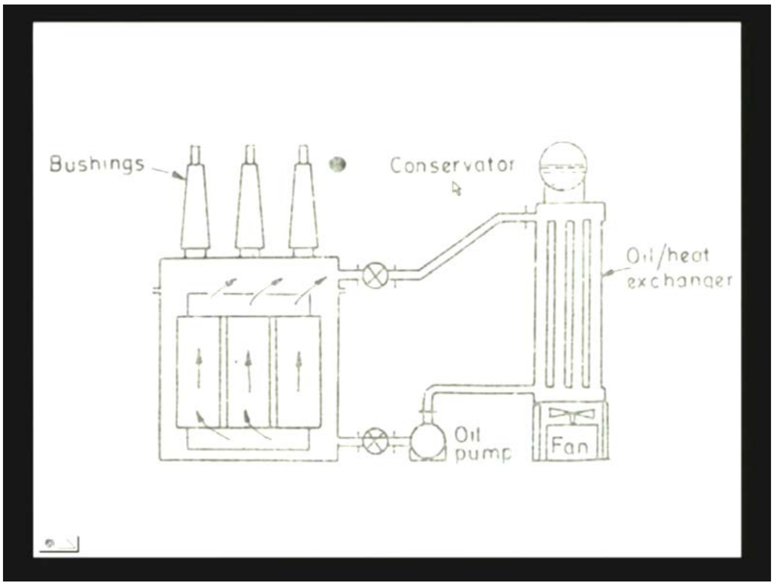


The next figure shows how an online tap changing can be arranged. So, this is let us say, a particular winding of the transformer with five tap positions. We want to go let us say from once the connection was at tap two; we want to go to tap three. For on load tap changing, it has to follow certain sequence; this is the selection switch. So, first the selections switch which was at position one and this position, then each of these taps are connected with a current limiting resistance. Well, it is supplying from tap two; it is the position of the switch is this. This resistance is shunted by this short circuit. So, current actually flows through this path and not through this resistance.

The first step in step tap changing is to move this switch from this position to this, so that this external connection is now removed from tap two, still connected to tap two but now through this resistance R a. Next we move to the position where these two resistances are shorted by this diverter switch. This is the reason why these resistances are necessary because without these resistances if we move this diverter switch then there will be a short circuit between these two taps, and there will be a large circulating current which may damage the part of this winding. So, these current limiting resistances are necessary.

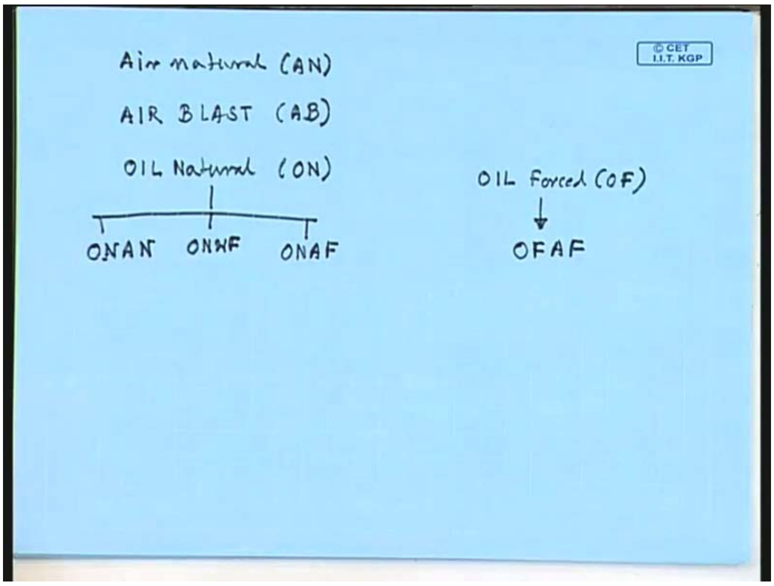
So, now current is flowing half of the load current is flowing from here, half of the load current is flowing from here, and there is a circulating current small i. Next we move to this position where tap two is completely disconnected, and tap three is connected through the current limiting resistance R b. And finally, we move here where this R b is shorted by the diverter switch. So, this is the sequence of operation by which one can do online or on load tap changing that is without disconnecting the transformer from the load.

(Refer Slide Time: 21:45)



We have mentioned in one of these slides that it is necessary to circulate cooling fluid through the windings and the core of the transformer in order to prevent the temperature of the transformer rising to a very high level. Now there are different methods of cooling. For small transformer dry type, it is usually not necessary to use any separate cooling medium; the transformer is left outside, the ambient air is sufficient to cool the transformer.

(Refer Slide Time: 22:34)



This is called air natural cooling AN. On a slightly high rated transformer, a natural air circulation may not be sufficient to prevent temperature rise of the transformer in which case the transformer may be cooled using a fan. This is called air blast cooling except for a very special applications where using a cooling medium is hazardous, these are used only for small rated transformer. For a large majority of transformers they are usually oil immersed, and the transformer oil works as a medium of cooling. Thus figure shows such an arrangement. These are the transformer core and winding; this is placed inside a steel tank, and the tank is filled with transformer oil.

The reason for using oil is that it is a better conductor of heat than air, and it has a higher coefficient of volume expansion with temperature. Therefore, sufficient circulation is easily obtained on account of natural thermal head that occurs in the transformer because of heat produced by different mechanisms of loss such as the core loss and the copper loss. So, the natural cooling by oil works this way. As the oil hits up becomes lighter moves upward and comes in contact with the transformer tank wall through which coming to the transformer wall; this heat is designated to the ambient. This is called oil natural cooling.

Now for smaller rated transformers a simple transformer tank is sufficient to provide this cooling; however, for larger transformer the surface area provided by the tank alone is not sufficient. And therefore, the tanks area is usually supplemented by a large number of either the tank surface is corrugated to increase the surface area; more commonly circular or elliptical tubes area placed on the transformer tank, all around the transformer tank in order to increase the cooling area. This has several categories. This is called oil natural, air natural because neither the oil or nor the air is forced through any pump or any other device.

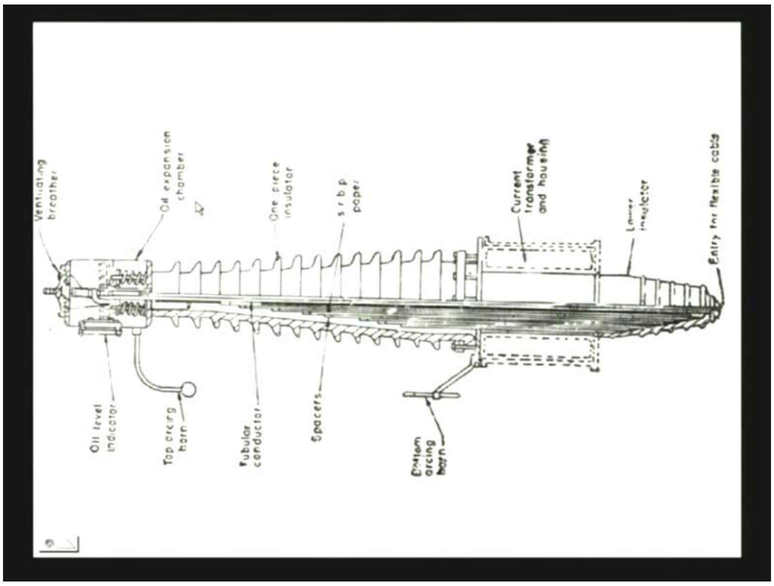
However, for larger transformer natural cooling by air is not sufficient in which case it becomes necessary to blow air to cool the heated oil. For this normally the transformer, the hot transformer oil is carried to an external heat exchanger through piping arrangement. And the heat exchanger is where the heat is transferred from the oil to surrounding air, and it is usually cooled using a fan. This method is called oil natural air forced. And this heat exchanger can also be cooled by forcing water circulate around the oil carrying pipes, then it will be called oil natural water forced. This is used normally in hydroelectric generating stations for the generator transformer, because a large quantity of water at a sufficient head is available and water is a better medium of cooling than air.

For even larger transformer, the normal thermal head of a transformer is not sufficient to provide enough cooling of the transformer; therefore, the oil is circulated through the transformer through by using an oil pump, the rest can be similar to oil natural air forced. So, this oil pump circulates the cooling oil through the transformer at a given flow rate in order to remove the heat generated from the transformer faster. So, this is called oil forced cooling method. Oil forced cooling method is usually used with a heat exchanger which is cooled by fan. So, this complete scheme will be known as oil forced air forced such a scheme is shown in this diagram. It is interesting to note that this scheme can operate in variable mode.

For example, the oil pump and the fan need not be on all the time. If the transformer is likely loaded and dissipating less heat, then both the oil pump and the fan may be turned off, and the scheme can work in an oil natural air natural cooling method. If the load increases to some more extent then may be the fan will be turned on first, so that it will work as an oil natural air forced method. It is only at near about rated load or at rated load that it will work as oil forced air forced cooling method. This way the power consumption for cooling will come down, and the overall efficiency of the transformer will increase.

The next important constructional feature of a transformer is its bushings; these are the bushings. These bushings are meant for making connection to the transformer from overhead lines. It has to be ensured that this transformer tank is normally earth. So, when you are making high voltage connection through the tank to the transformer winding it has to be ensured that there is no flashing or short circuit or otherwise degradation of the insulation between the high voltage terminal and the earth transformer tank. This is done through special bushing.

(Refer Slide Time: 31:32)

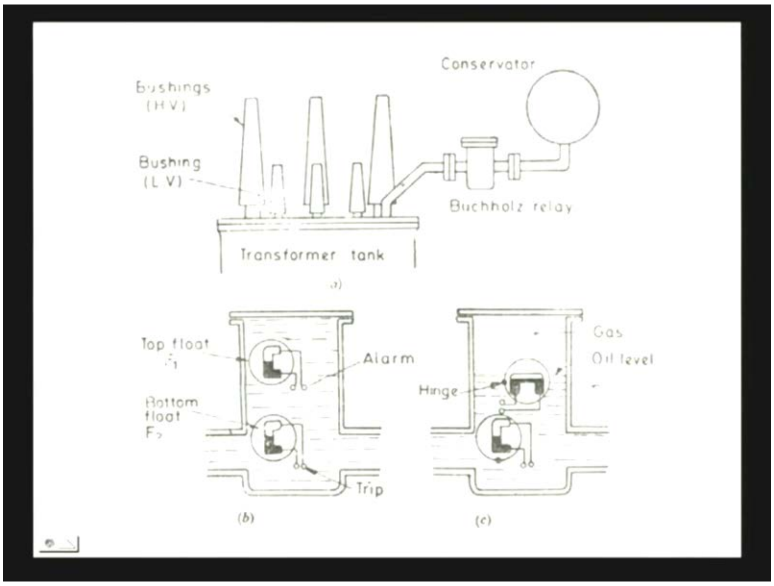


This figure shows the construction of one type of bushing called the oil filled bushing. There are two types, the oil filled type or the capacitor type. This is for an outdoor transformer. The bushing in its simplest form is an insulated housing mostly a porcelain with a hollow space in between through which the connecting wire or the rod can be placed. So, this is the bushing. These are the porcelain discs which provide the insulation. So, from the top to the bottom here is the entry of the cable, and this is the conductor. These are normally oil filled with an expansion chamber on the top and also provided with arcing horns. So, that if there is a flash over it occurs between this arcing horns.

It is also provided with a current transformer which measures the current flowing through the terminal. These protrusions for of the porcelain cylinders provide for extended insulation and prevents against corona. This tank this is normally oil filled; this provides a space for expansion of the oil so that with variation of temperature, and this normally is insulated with s r p b paper. So, this is the construction of oil filled bushing. There is a another type of bushing construction which is called the capacitor type in which alternate layers of metallic conductor, and insulating material are owned in a cylindrical fashion to form a series of capacitor between the inside conductor high voltage conductor and the outside plane which is normally earth.

So, the potential distribution along the radial direction of the bushing is equally divided. For three phase transformer there will be three such bushings, and the first figure these are the bushings for external transformer that are used for outdoor operation, there will be this porcelain petticoats which prevents again rain and dirt pollution. For internal or indoor transformer these porcelain cylinders are smooth.

(Refer Slide Time: 34:56)

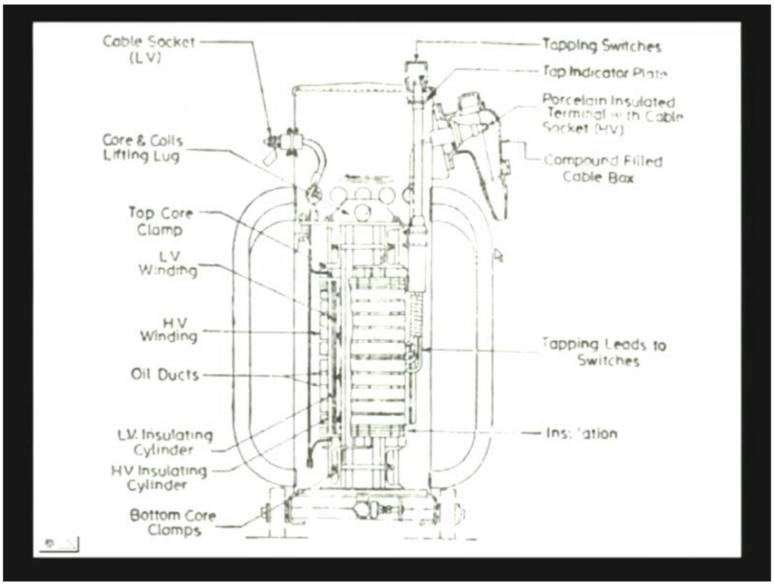


The transformers are to be also provided with sufficient protections. The electrical protections are normally provided by relays. Here is one arrangement that provides a protection against transformer over current or short circuit; this is provided by what is called the Buchholz relay. This figure shows the construction of a Buchholz relay. This usually consists of a chamber which is normally filled with oil, and it consists of two trip floats which hold two conductors. In the normal situation this chamber will be filled with oil and both the floats counters will be open.

However, if there is some short circuit some fault, so that there is over current in the transformer. Gases will be generated because of heating of the transformer oil. And since this is filled with oil, the gas will move up and will push the oil level down; as a result this is hinged. So, this will turn around; the top float will turn around and will possibly close a contact here. So, which will sound an alarm and tell the operator that something is wrong; however, the normal over current or over current for small duration will not produce enough gas to make the bottom float operate.

This will happen only if there is a severe or a direct short circuit and violent gas generation, then the level will go down further, and even the contact of the bottom float will be closed. This float is a connected to trip circuit which will close the tripping circuit of a circuit breaker, and the transformer will be disconnected. So, this Buchholz relay is used with many large sized three phase transformers.

(Refer Slide Time: 37:25)

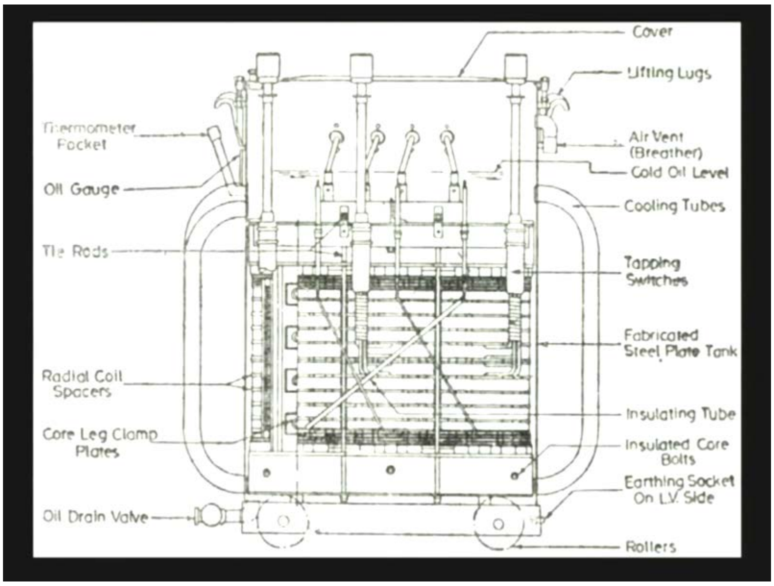


So, here we can see the final assembly of a three phase transformer. The different parts are this is the transformer tank which is visible from outside. These are the cooling pipes. Inside this tank this is the oil level; this is the actual core and winding configuration. So, this is the top core clamp; this is the LV winding; this is the HV winding; between HV and LV there are oil ducts. This is the LV insulating cylinder here; this is the HV insulating cylinder here the bottom core clamp, and these are the tapings. These are different insulating material.

Now this does not show a bushing because the underground cables may be connected through this cable box, and this also has porcelain insulating terminals but does not show a bushing. And there is a provision for seeing where the tap position is, and this is the tap switch. This is one view of the transformer. The second view is this. This is the front view. This mostly shows the other auxiliary connection; for example, the cover, the lift lug. There is an air vent or breather. Note that there is a conservator on the top of the tank. This conservator is normally the tank will be completely filled with transformer oil. In fact, the transformer oil will also feel the Buchholz relay will possibly end somewhere here.

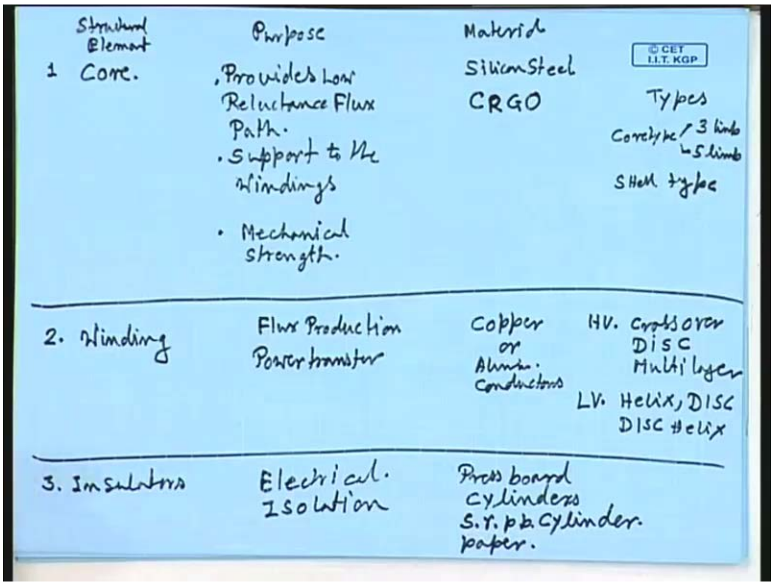
The reason why it is done is that so that the minimum of the transformer oil surface comes in contact with air, and it does not absorb moisture from the air. The conservator provides the space for expansion of the oil. As the transformer hits up, the oil expands and flows through the tube to the conservator. Now this conservator while although it is not shown here is connected to the external atmosphere through what is called a breather. So, this is the conservator. Conservator will normally have a pipe extending down. This is called the breather, and the breather in there will be a cylinder like this. This cylinder will contain silica gel, so that the air that comes in or out of the convertor is always through this silica gel which absorbs moisture. So, the contamination of the transformer oil due to atmospheric moisture in the atmospheric air is minimized.

(Refer Slide Time: 41:23)



So, this is the breather; this is the cold oil level here. It is above the transformer that the cooling tubes. This is again the tapping switches here; this is the steel tank; this is the core clamps; these are the insulated bolts, and this is the earthing socket. See the transformer oil needs to be periodically changed. So, there is an oil drain valve. These are the coils. You can place an oil gauge here, and there is a provision for inserting a thermometer, so that you can measure the temperature rise of the oil from outside. So, this more or less summarizes the main constructional features of a three phase transformer; the main parts of which we can summarize as follows.

(Refer Slide Time: 42:46)



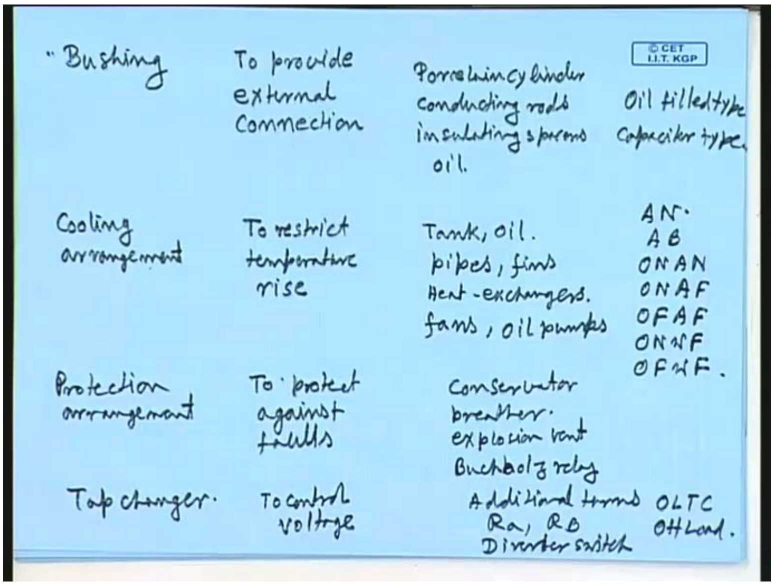
The main parts of the transformers are one is core. The purpose of this core is to provide low reluctance flux path also provides support for winding. So, these are the purpose. This is the structural element. This is the purpose. This also provides support to the winding as well as provides structural or mechanical strength. It should be realized that the transformer windings are subjected to substantial mechanical forces particularly during abnormal operating conditions such as faults. And they should be design to withstand such mechanical forces. The materials for the core are silicon steel, normally cold rolled grain oriented CRGO. This is oriented in the direction in which the flux is expected to flow, and there are different types.

For example, it can be core type which can again be either three limb or five limb, or it can be shell type. So, this is the types of cores. The next important feature is the winding;

important construction feature is winding. The purpose of this is flux production and power transfer between input and output. The material used are either solid or stranded copper or aluminum conductors, may be solid stranded conductors or strips. There are different types of winding; HV winding can be of cross over, disc, multilayer. LV winding can be of helix disc or disc helix.

Third important constructional elements are the insulators provide electrical isolation between different parts. The materials used are press board cylinders, SRPB cylinders. SRPB stands for synthetic resin paper and transformer oil. There are two types of insulators. One is called the major. This is between different windings, core and winding and between phases and minor which is between different parts of the same winding, and the third type is the oil barrier, in short which is the insulation relative to the tank?

(Refer Slide Time: 48:46)



And next important structural element is the bushing. The purpose is to provide external electrical connection. The materials are porcelain cylinders, conducting rods, insulating spacers, oil. These are two types, oil filled type and capacitor type. Then you have cooling arrangement. To restrict temperature rise the medium of cooling are the material or components required for cooling are tank, oil, pipes, fins, heat exchangers, fans, oil pumps. These are the components required for the cooling arrangement, and you have different types of cooling. For example, air natural, air blast, oil natural air natural, oil natural air forced, oil forced air forced, oil natural water forced, oil forced water forced.

These are different types of cooling. They are used with increasing rating of the transformer. This is for the lowest rating; this is for the highest rating transformer. Then protection arrangement to protect against faults, and you have all kinds of arrangement for this. The conservator prevents explosion, breather, explosion vent, then temperature in Buchholz relay, temperature indicator, etcetera, and then last is the tap changer. So, this is to adjust to control voltage. So, you have to have additional turns, current limiting resistance R a, R b diverter switch. This again can be of two types. One is on load and off load tap changers. So, this in nutshell summarizes the basic constructional features and their purpose and types of three phase transformers.

Thank you.