Power System Protection and Switchgear
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Lecture-26
Protection of Transformers-I

Okay. So, let us discuss the next lecture that is on transformer protection. So, we know that the faults are inevitable, if you use transformer as one of the equipment.

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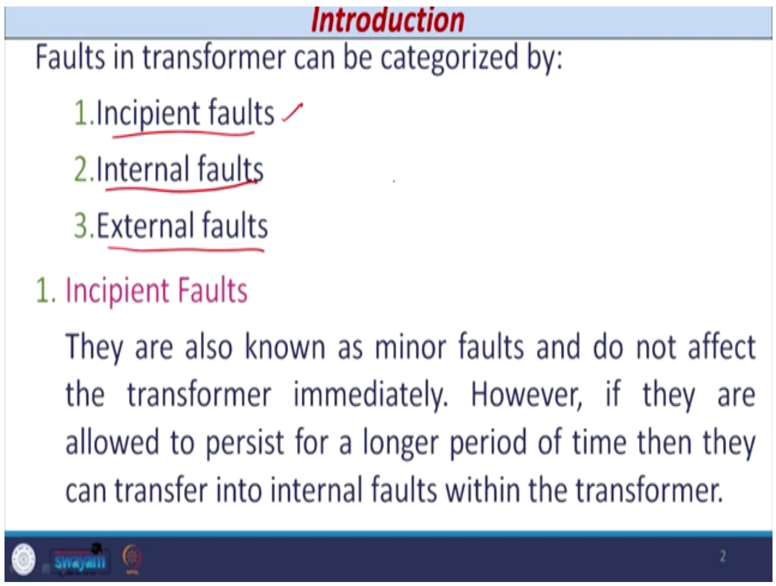

Then there are different types of faults that may occur in the transformer. So, these faults are categorized by first that is known as the incipient faults. The incipient faults are also known as minor faults. So, usually they do not occur inside the winding or core of the transformer. So, that is why these faults are known as in incipient faults or minor faults.

The second type of fault that is known as the internal faults or electrical faults, which occur in the winding and the core of the transformer. And the third type of fault that is known as the external fault, this type of faults occur outside the transformer, and this faults are not part of the transformer itself.

Now, let us start our discussion with the first type that is the incipient faults. So, in, as I told you earlier, the incipient faults are also known as the minor faults, means if we wish to detect this fault, we have to use separate device. And whenever such type of fault is detected that there is no hurry that we have to trip the transformer immediately. But if this type of faults persist for a longer period of time or longer duration, then this type of false may be converted into the actual electrical faults or internal faults of the transformer. So, there is a need to detect such type of fault.

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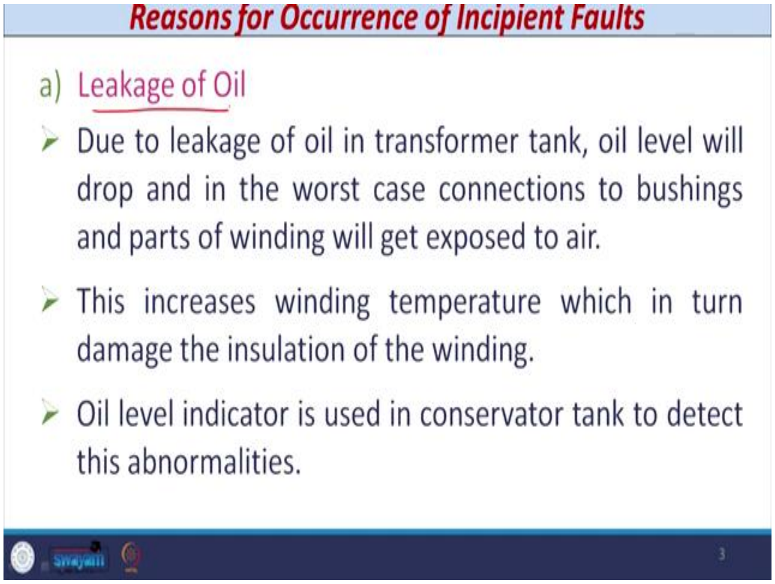

So, let us see what are the reasons because of which incipient faults may occur in the transformer. So, the first reason that is known as the leakage of oil. So, we know that due to the leakage of oil in the transformer, the oil level that may drop and in worst condition, the bushings and the other parts of the winding, they may expose to the air. So, this increases the winding temperature and which in turn finally damage the insulation of the winding. So, how to detect this leakage of oil, so to detect leakage of oil, oil level indicator is used in the conservator tank of the transformer. And this type of abnormality can be easily detected.

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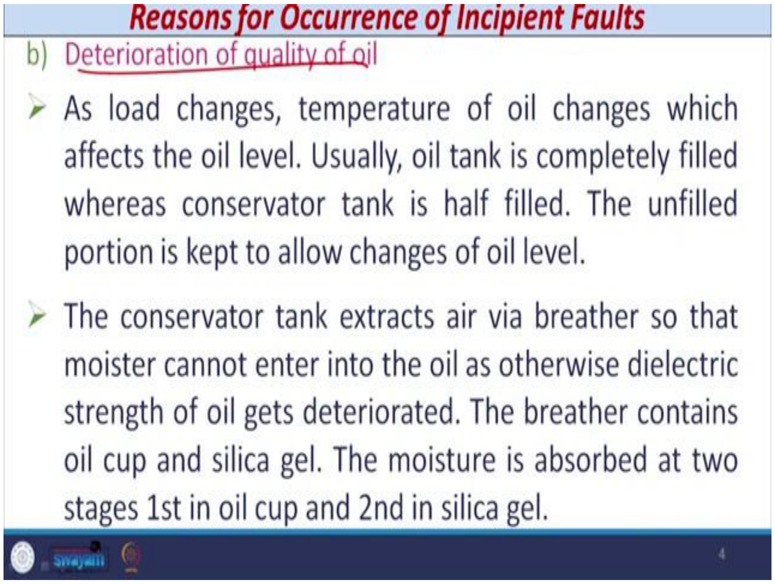

The second reason that is the deterioration of quality of oil. So, we know that the transformer has 2 tanks, one is the main tank itself, and the second is the conservator tank. So, the oil tank or the main tank of the transformer that is completely filled, whereas the conservator tank of the transformer that is half filled.

The reason for a half filling of the conservator tank is to allow the changes in the oil level because of the change in load. So, the conservator tank extracts the air, via breather so that moisture cannot enter into the oil because if moisture entered into the oil, then the dielectric strength of the oil that will be deteriorated. So, breather contains basically two things oil cup and silica gel, so the moisture that is absorbed that can be easily cleaned at two stages, first from the oil cup itself and second in this silica gel. So, whenever we do the regular maintenance, we have to also check the silica gel and we have to carry out regularly cleaning of the silica gel. And if required, we need to change it also.

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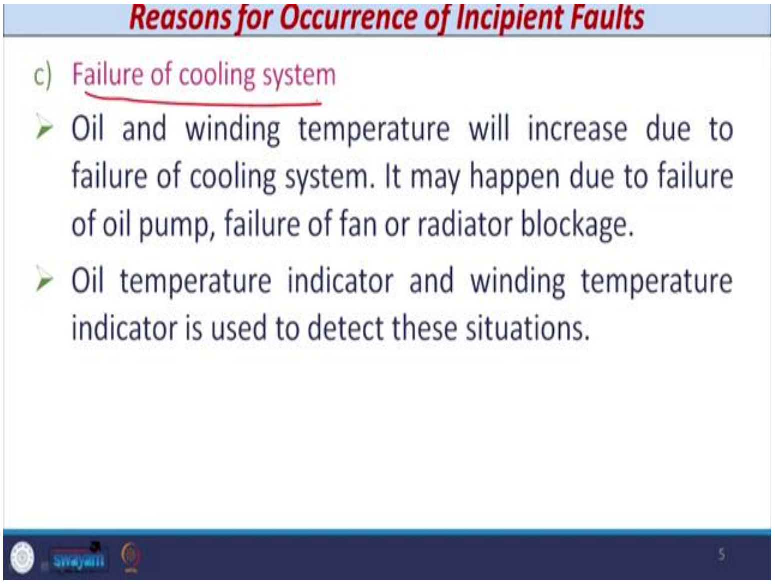

The third reason for the occurrence of incipient faults in the transformer that is the failure of cooling system. So, we know that, we are talking about the power transformer. So, the power transformers are very large transformers. So, the oil that is normally used for cooling, so because of the oil and winding temperature will increase due to failure of cooling system. And this may happen because of the failure of oil pump or maybe the failure of fan or the blockage in the radiator. So, to detect this type of abnormality oil temperature indicator and winding temperature indicator that is used inside the transformer.

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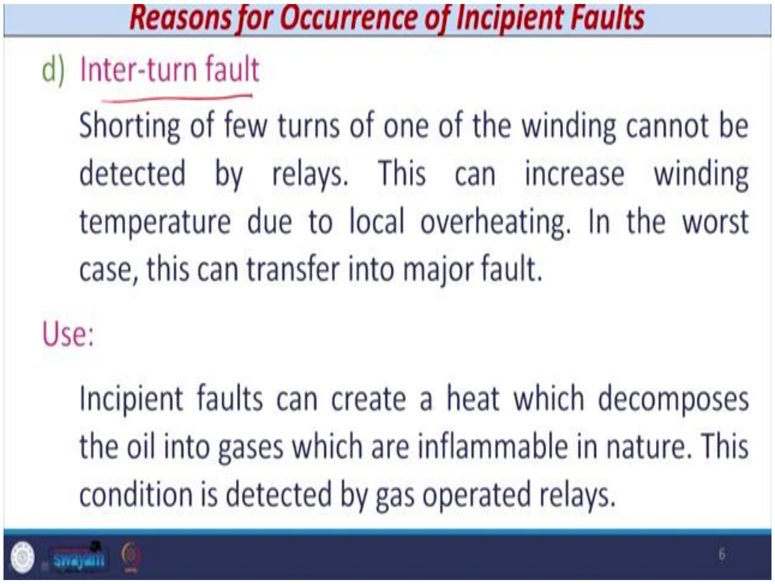

The fourth reason for the occurrence of incipient fault in the transformer, that is, nothing buddy inter-turn faults. So, wherever the few tons of one phase or the multiple phases shorted together, then there are a fair chances of increase in the temperature because of the local heating. So, in the worst case, this may transfer into the major fault and we need to detect such type of fault. Keep in mind inter-turn fault that occurs or happens in the particular 1 phase or multiple phases.

So, the, whatever protective device we use, normally differential protection that is not capable to detect such type of inter-turn or turn-to-turn fault. So, we need to detect this type of fault with separate device or separate arrangement. Now, let us see how to detect such type of incipient faults that occur in the transformer.

So, we know that whenever such type of incipient faults occur, maybe because of inter-turn fault or leakage of oil or maybe some other reason, then this type of fault produces heat. And this heat that is going to decompose the oil into the gases and these gases are inflammable in nature, which may create hazard in the transformer. So, this type of condition need to be detected. So, in actual or real field, this type of incipient fault or condition that can be detected by gas operated relays.

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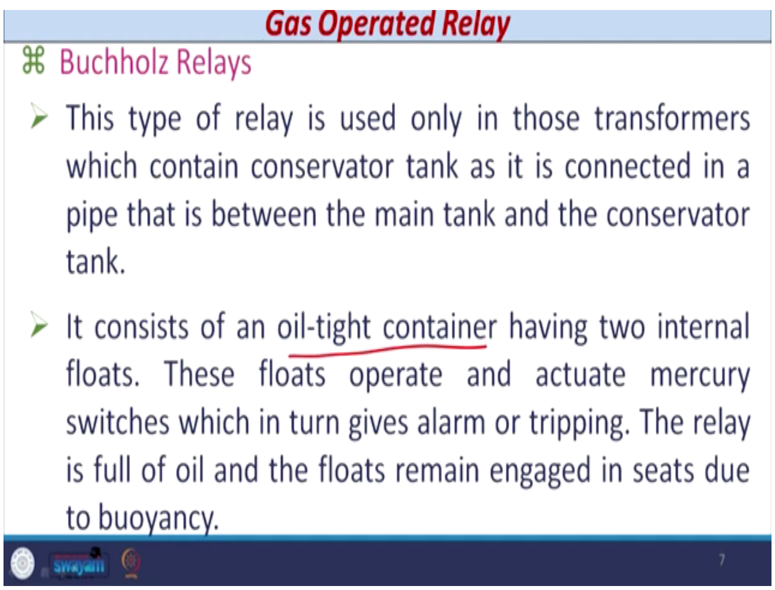

So, let us discuss now the working of the gas operated release. So, there are two types of guests operated relays. One is known as Buchholz relay and the second that is known as the sudden pressure relay. The Buchholz relay is the relay, which is normally connected between the pipe connected between the conservator tank and the main tank of the transformer. So, this type of devices are utilized particularly in our country. Whereas the sudden pressure relays are not connected between the conservator tank and the maintain tank hence it is used in some other countries.

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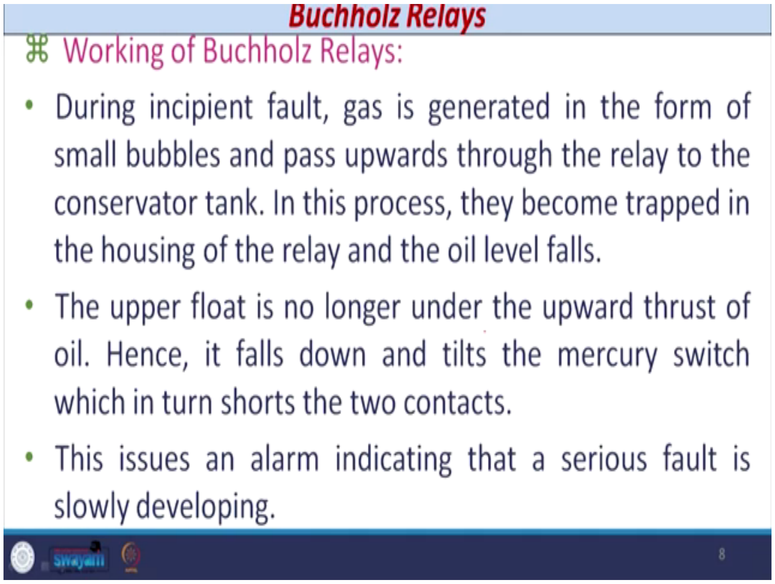

So, now let us discuss what is the working of the Buchholz relay. So, the Buchholz relay consist of the oil tight container and this in oil tight container, there are, two floats are provided these two floats operate and finally actuate the mercury switches below the each float, the mercury switches provided. So, there are two floats. The one float that is known as upper floor and the other float that is known as the lower float.

So, the relay that is full of oil and the floats remain engaged in their seat due to the UNC effect. So, let us discuss the working of the Buchholz relay. So, during the incipient fault, gas is generated in the form of small bubbles and they pass upwards to the relay and whenever they become trapped in the housing of the relay, the level of the oil that falls.

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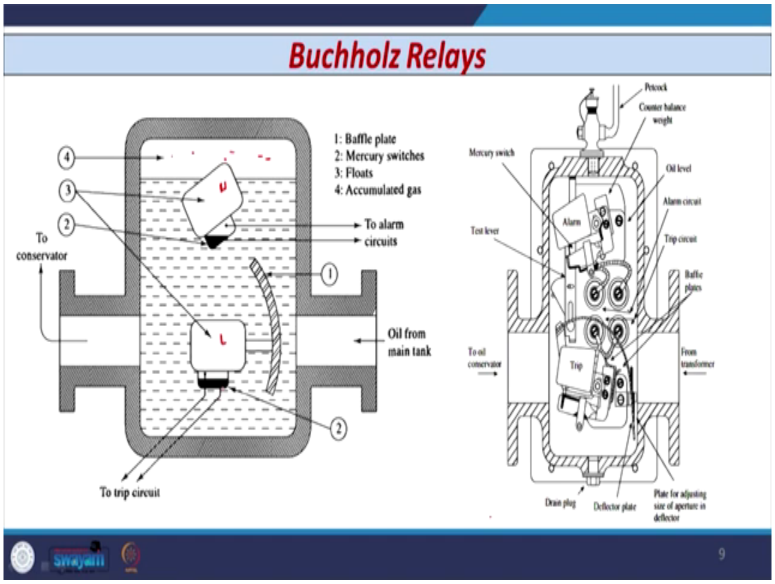

So, if I consider the diagram, you can see in this diagram, there are 2 floats provided. This is the upper floats, and this is known as the lower floats below each float. The mercury switch is provided that is also shown here and along with this mercury switch, the upper float that is meant for the alarm circuit. That means to indicate the alarm that some type of minor fault that occurs. So, operator has to take certain action or decision.

On the other side, the lower float below the lower floor, mercury switch is also provided and lower float is meant for the tripping circuit. So, whenever the formation of gas or bubbles that is in large than the lower float comes in picture. Whereas the formation of bubble that is very slow, then the upper float that comes in picture.

Now, you can see along with this lower floor, there is another plate known as baffle plate that is also connected. And you can see that this Buchholz relay is connected between the, on the right-hand side, you can see the oil is coming from the main tank and on the left-hand side, the oil that is going to the conservator tank.

So, whenever the very small minor fault that occurs in the transformer then what will happen, this upper floor, whatever is thrust provided by the oil that this will no longer remain in this original position, which is there because of UNC effects. So, the oil level drops because of formation of bubble and bubbles are somewhere here.

So, because of this upper float balance of the upper float get disturbed and hence the, it actuates the mercury switch just below it. And hence it will issue the alarm circuit. So, this is how the upper float comes in picture and it issues an alarm wherever the, any incipient faults that occurred that is in severe mode then the lower float comes in picture, the oil level drops suddenly.

So, what will happen balance of the lower float gets disturb and below this lower float, the mercury switch is provided. So, it actuators the mercury switch, which finally initiate the trip circuit. So, trip coil of circuit breaker is energized and which in turn the isolate the transformer because of the operation of the circuit breaker. So, this is how the Buchholz relay works. Now, let us see, what are the drawbacks of the Buchholz relay?

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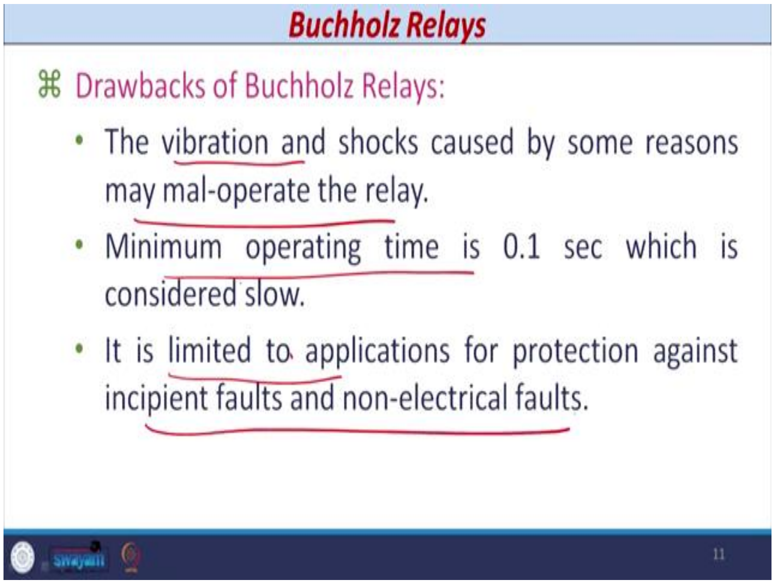

So, the very first drawback of the Buchholz relay is the whenever the vibration or shocks are there, maybe because of many reasons like earthquake or maybe some mechanical vibrations are there, then such type of relay may mall operate. So, we need some arrangement to avoid such type of mall operation.

The second disadvantage is the time of operation of Buchholz relay, that is of the order of 0.1 second, or 100 millisecond and that is considered to be lower compared to the other devices used in the transformer. The third is the, this type of application of Buchholz relay that is limited for the protection against incipient faults or the non-electrical faults. So, this type of relays cannot be used for the protection of transformer against the electrical fault or internal fault in the winding or core of the transformer.

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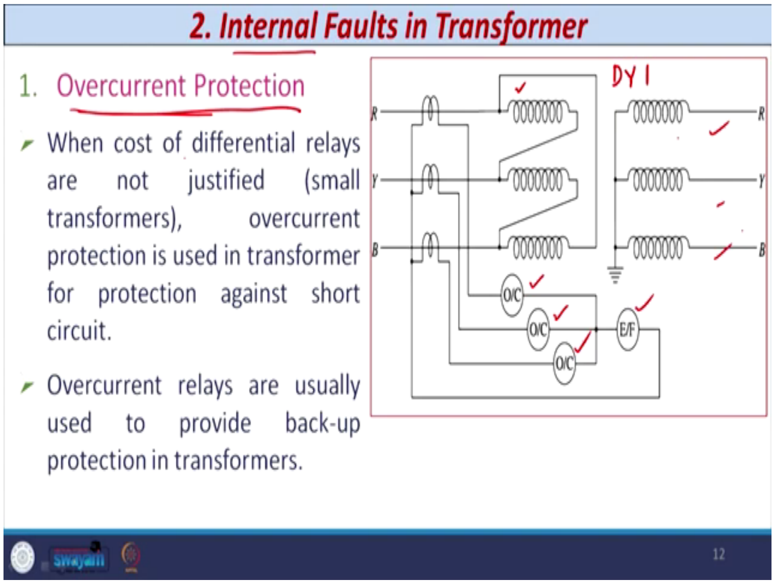

Now, with this background, let us consider the second type of fault that occurs inside the winding of the transformer and core of the transformer. So, this faults are known as internal faults or electrical faults that occur in the transformer. Now, the first type of protection we provide against the terminal fault in the transformer that is known as the over current protection. Now, we know that there are different, if we classified the transformer then transformers can be classified as the power transformer and the distribution transformer.

So, whenever the cost of the differential relays, because normally we use differential relay in the power transformer for the protection against any type of short circuit. However, when we use the distribution transformer, the cost of distribution transformer itself is not that that comparable with the power transformer. So, differential relay cost is also very high. So, we use the differential relay only for the protection against short circuit in case of power transformer.

But when we go for the distribution transformer then we cannot use the differential relay. Because as I told you earlier that we have to use a particular protective device only when the cost of that particular protective device is almost 10 to 15 percent of the cost of the equipment to be protected. So, in this case, when we have a condition, like when we use distribution transformer and we need to protect that against short circuit, then we need to go for the other type of protection other than the differential protection.

So, for that, we will go for the over current protection and for the over current protection, we can see there is a, I have shown 1 figure that is the delta star transformer, it is a 3 phase diagram, and this is a DY1 connection, delta star one connection of the transformer. Now, you can see that on the delta side of the transformer, this side, I have connected the 3 CTs. These are the 3 lines CTs, each CT that is connected in 1 phase. And along with the each secondary of this CT, I have connected the 3 over current relays, 1 in each phase and 1 earth fault relays.

So, whenever any short-circuit occurs on the delta side of the transformer then the over current relay detects if the magnitude of current exceeds the pickup value and hence it gives further signal so that it disconnect the breaker. Keep in mind such type of relays are used on the delta side of the transformer. Similarly, we need to protect the star connection of the transformer also. So, on this side also, we need to use some other protective device. Again, this is only for the case where the cost of the protective device that is not very high. That means we cannot use the differential protection that is for distribution transformers.

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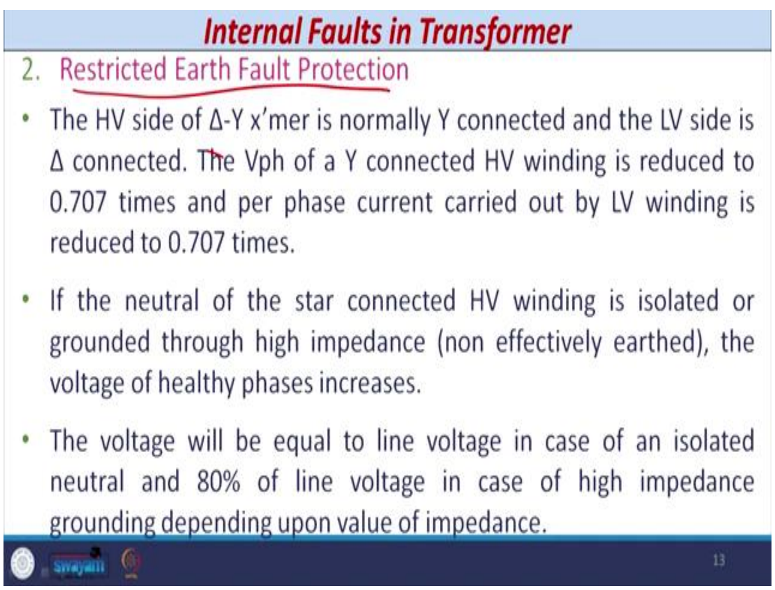

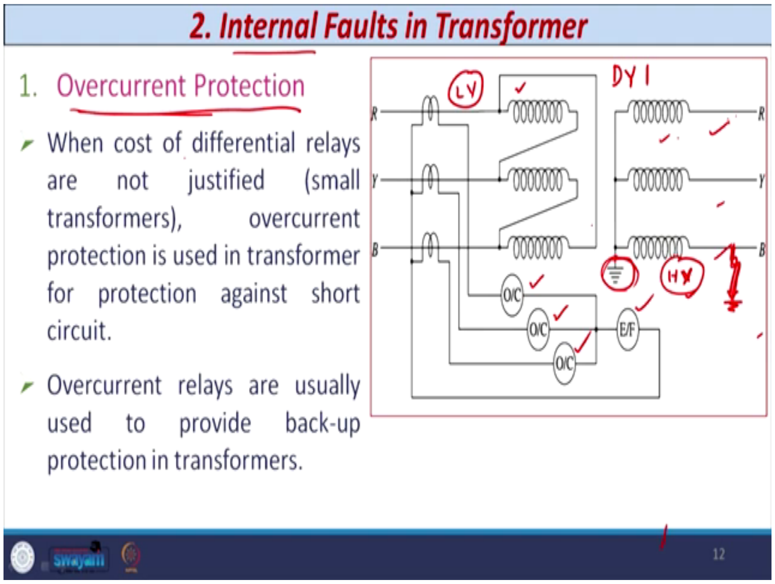

Now, let us discuss the second type of protection that is known as the restricted earth fault protection. Now, before we proceed such type of protection, we need to consider the concept of the grounding. So, whenever we consider the star delta transformer, the star side that is the HV side that is always star connected. So, if I consider the delta star transformer having connection 1 o'clock then the star side, this side that is always the high voltage side and the delta side that is always the low voltage side.

What is the reason? The reason is that if I use, if I put the star side, that is the high voltage side, then whatever voltage, phase voltage that will be reduced root 3 times, with reference to the line voltage. And if I, phase current if I consider on the delta side or LV side winding, that is also reduced root 3 times. So, this is the reason for star delta power transformer always HV side is star connected and LV side is delta connected.

Now, if I further consider the star connected, that is HV side of the delta start transformer, then this on star side you can see there is a grounding point. So, this star point that can be isolated or that can be connected solidly, or maybe connected through some impedance. So, if the neutral of the star connected delta star transformer is isolated this is not the common practice, it is never be isolated because if it is isolated then the voltage whenever fault occurs on this side, say any line to ground fault occurred somewhere here, any B to core fault then the healthy phase that is R phase and Y phase voltage that will become the line voltage.

So, the insulation requirement that increases. So, hence this is never be isolated. So, it is always connected or grounded. Now, there are 2 options, whether the star connection that is solidly grounded, or it is grounded through some impedance, whenever it is grounded through some impedance, it is known as non-effectively earth system. And when it is solidly grounded, it is known as the effectively earth system.

So, if I consider the, that the neutral is grounded through the some high impedance, or when I consider the neutral is solidly grounded then each has certain advantages and disadvantages. If I consider the first case, when the neutral is solidly grounded, then the magnitude of current is very high. But on the other side, if I consider the same case, then the, whenever the, any fault occurred somewhere here, then the healthy phase voltage that is not going to increase to the line voltage because when this transformer on right hand side of this transformer, this transformer is located in switchyard.

And along with this, the very high voltage transmission lines are emanating. So, whatever insulators are provided on the switchyard for this transmission line, this insulation requirement is not restricted only up to this point, but it is also applicable to the line insulators. So, that is why this is always either solidly grounded or grounded through impedance.

But if I consider the second case that this is grounded through some impedance, and if any fault occurs, then the healthy phase voltage that may increase and that depends on the value of the reactor or resistor connected here in the ground. So, if I consider, if I connect through this ground through the some impedance, then of course, obviously, the magnitude of fault current reduces.

But at the same time, whenever such this fault occurs, the other 2 healthy voltages that will go up to the 80 percent or line voltage. And that is not restricted and only up to this point HV winding of the transformer, but as I told you, it is also applicable to the adjacent equipment that is the line insulators for the lines emanating from this switchyard.

So, that is why because of, to save the insulation requirement, this neutral, this star point of this HV side of the star delta transformer is always solidly grounded. The only disadvantage is whenever any fault occurs, earth fault occurs on star side than the magnitude of current that is very high. But anyway, that we can afford against the insulation requirement, which increases the cost.

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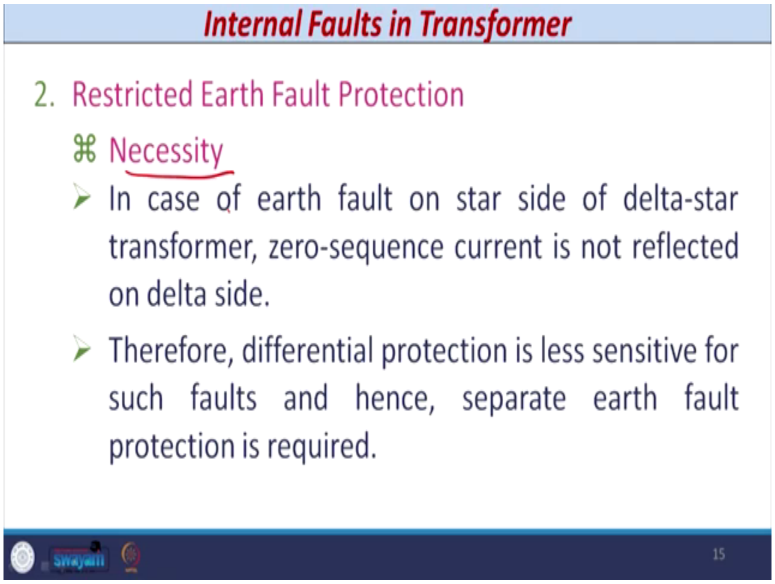

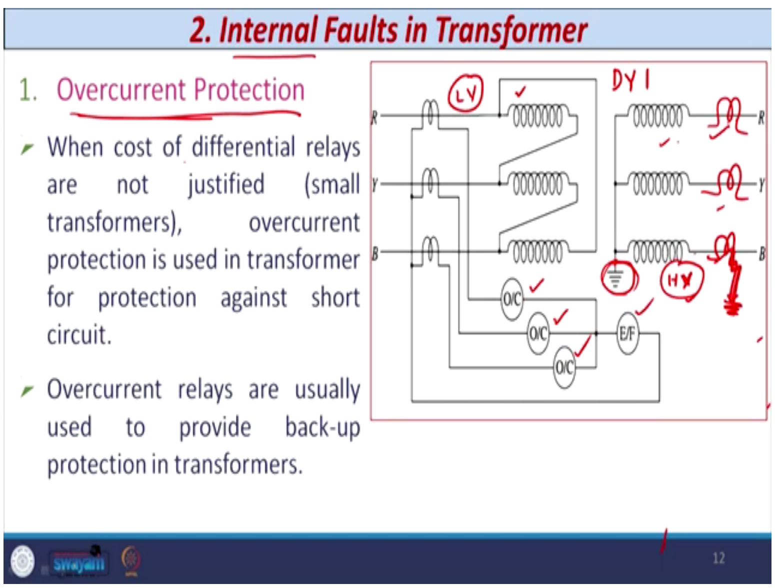

So, to understand the restricted earth for protection, let us consider the main important point. Let us see first, what is the necessity of the restricted earth fault protection? So, as I told you, if any fault occurs on the star side of delta star transformer, then zero-sequence current that is not reflected on the delta side.

So, you can see here, if any fault occurs, ground fault or earth fault occurs then the whatever is the zero-sequence current that is not reflected on this side. So, if I use the differential protection, 3 CTs here, and 3 CTs here. And if I give the secondary currents to the relay, then as this zero-sequence current are not reflected or comes out of the delta winding. So, differential protection that is not capable to detect such type of earth fault on the star side of the delta star transformer.

So, to protect this because different, as I told you, differential protection is not that much sensitive. So, we need separate protection for any fault for detection of any fault on the earth side of the delta star transformer. So, for that restricted earth fault protection that is used.

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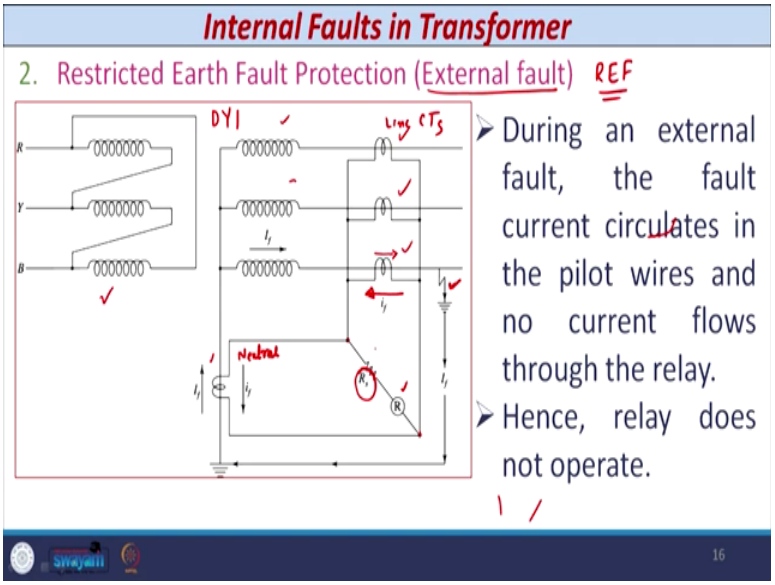

Now, let us discuss, how the restricted earth fault protection that is applied on the star-delta transformer. This is basically the power transformer. Now, this type of scheme is also known as the REF scheme, that is, restricted earth fault scheme of protection. Again, I have considered the delta star one transformer. So, the LV side that is the Delta connected, you can see here and the star side, on this side, it is solidly grounded. And I have again connected the 3 line CTs. And I have also used one neutral CT and the secondary of this neutral CT, this is your neutral CT and this is the line CTs.

So, the secondary of 3 lines CTs and the neutral CTs that is connected at this common point. And at this point between these 2 points, the relay, whatever we call, whether we use over current relay or different type that is connected along with some resistance RS, this resistance is known as stabilizing resistance. This type of resistance, stabilizing resistance that is connected in series with the relay or relay coil, just to ensure that the relay should not operate in normal condition, or when there is no earth fault.

Now, let us consider the working of the restricted earth fault protection scheme. So, let us discuss first the working in case of external fault. So, this is the external fault. So, let us assume that one fault occurred somewhere here, outside, right hand side of the line CTs. So, whenever such type of fault occurs you can see that the direction of fault current on the primary of this CT, that is like this so the secondary current that is IEF is like this.

So, you can see that this current will flow like this. So, as the magnitude of current through neutral CTs like this, so secondary side of this neutral CT, the current, flow of current is like this. So, the direction is like this, this current will flow like this. So, you can see that in this fault on this side, which is external fault, no current that flows through the relay and hence relay will remain in stable condition. It does not operate.

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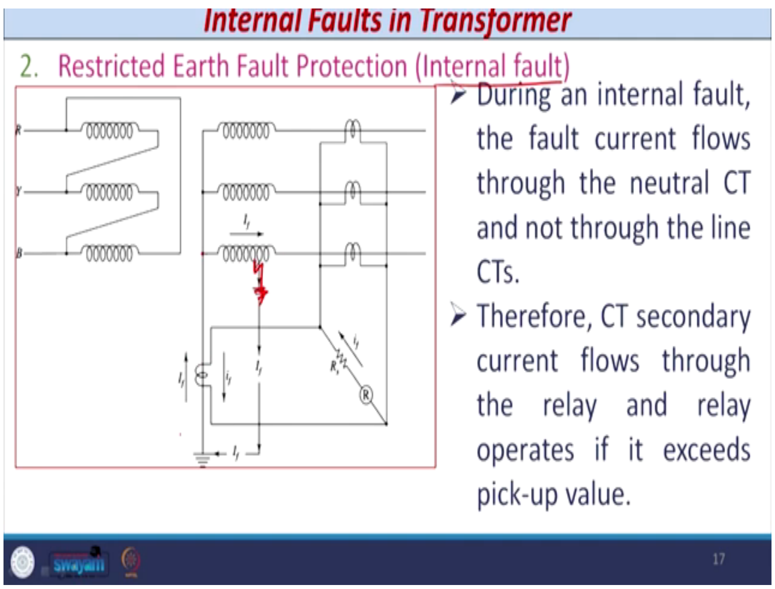

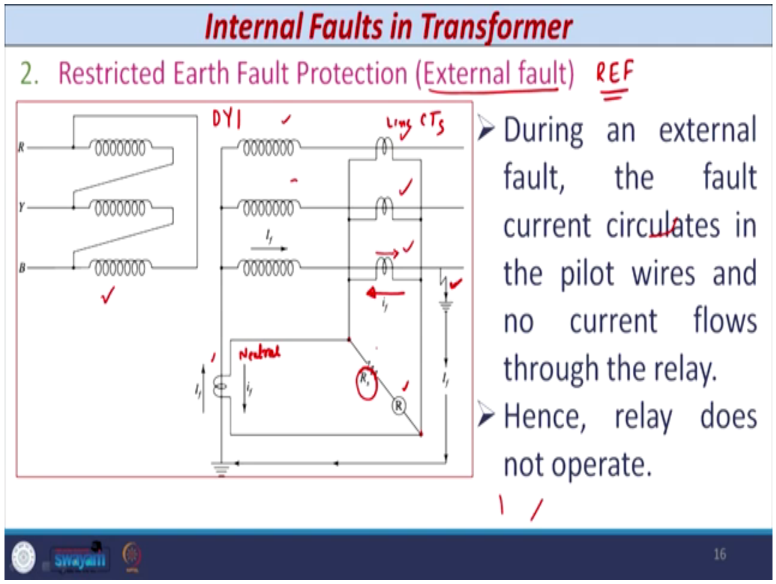

Now, if I consider the second case, that is the internal fault that is somewhere here inside the winding to the ground, then you can see that the direction of fault current is like this. So, as we can see the direction is from this point to here, to the fault point, to the, this ground and then back to this. So, you can see that as the direction is like this, the current, fault current flows only through the neutral CT.

Whereas in earlier case fault current flows through the neutral CT, you can see here as well as the, one of the line CT. So, here as the fault current flows through the neutral CT, so this secondary of the neutral city, small IEF that will flow through the relay. And if this current exceeds the pickup value or pluck setting of the relay are then relay operates.

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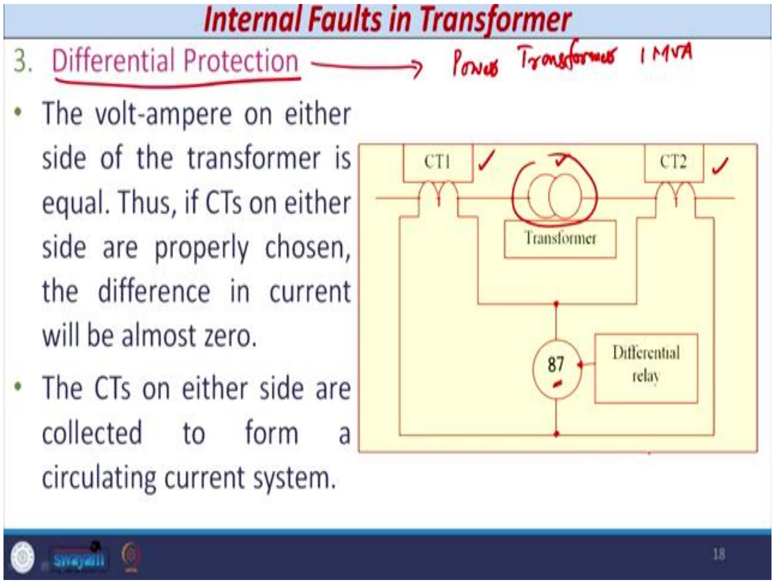

Now, with this discussion, the third type of protection that is known as the differential protection. So, differential protection that is widely used for the protection against the short circuit in case of power transformers. So, this is used only in case of the power transformer whose rating that is normally about, roughly about 1 MBA. Maybe around this, you can use such type of differential protection.

Now, that whenever we apply differential protection to the transformer, then few things or few factors we need to consider. So first, let us discuss, how we can apply such type of protection. So, you can see here, this is the transformer, which we need to protect winding of the transformer. And on each side of this winding of the transformer, I have connected the CT, CT1 and CT2, and the secondary of CT1 and secondary of CT2 that is given to the here. And at this point, the relay is connected that is known as the differential relay, the standard number for differential relay is 87.

So, whenever you apply such type of differential protection, you can see that the volt-ampere on either side, LV side and HV side are equal. However, the voltage ratio and the current that is different. So, whenever you apply such type of differential protection, you have to apply like this, and you can, you have to ensure that this relay should not operate in any external fault. It operates only in case of internal fault in the winding or core of the transformer.

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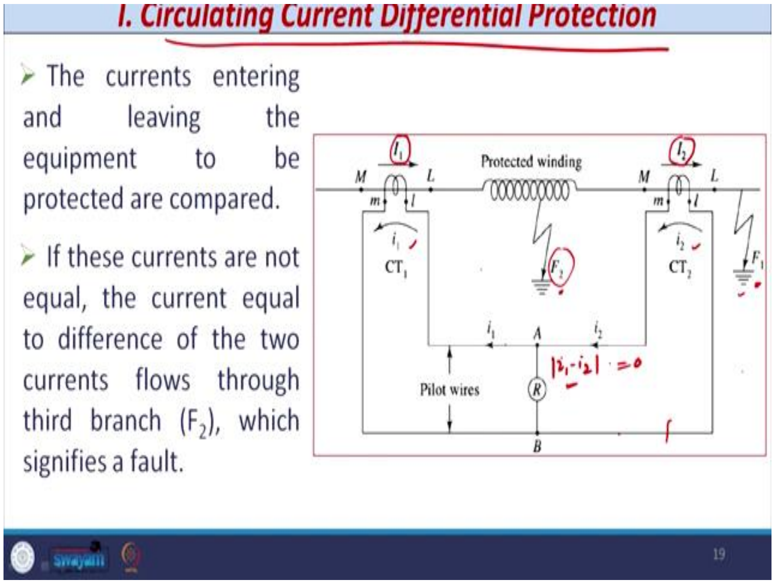

Now, the first type of differential protection that is known as the circulating current differential protection. So, I have shown here the diagram, this is the winding to be protected. It is only a single line diagram, so far only one phase. So, here the winding of the transformer and I have shown the, I have connected the 2 CTs, CT1 and CT2 here and the current through CT1 is capital I1, which is the primary current and current through CT2 that is capital I2 that is the, again, the primary current.

When you transfer this current on the secondary side it is small i1 and small i2. And you can see that this current that will flow here the capital I1 and small i1 are 180 degree out of phase. So, the current that flows that is like this and between point A and B, I have connected the relay. And through this relay the current flows that is the i1 minus i2, or i2 minus i1. So, it is i1 minus i2, let us take absolute value.

So, now you can, I have shown the 2 points. One is the fault at F1, which is known an external fault. And another that is this point, that is known as F2, that is the internal fault. So, how the circulating current differential protection scheme works? The principle is it works on the Kirchhoff current law, current entering to the winding that is capital I1 and current leaving to the other winding CT2 that is the capital I2 these 2 currents to be compared. If these 2 currents are equal then there is no internal fault path exist and hence this indicates the normal condition or external fault.

However, these 2 currents are not equal there is a significant difference is there between capital I1 and capital I2 or similarly the small i1 and small i2 that flows through the relay then the, obviously some internal fault path exist and relay has to take care of this. So, you can see that the, in case of external fault small i1 and small i2 are equal. So, the difference I1 minus I2, that is ideal 0, 0 current will flow through the relay.

Whereas in case of internal fault that is at F2, as the I1 and I2 are not equal. So, the difference I1 minus I2 that is significant. And if it exceeds some value, say pickup value or plug setting of the relay then relay operates. So, ideally this current should be 0 when there is no fault or external fault. However, this is not possible practically.

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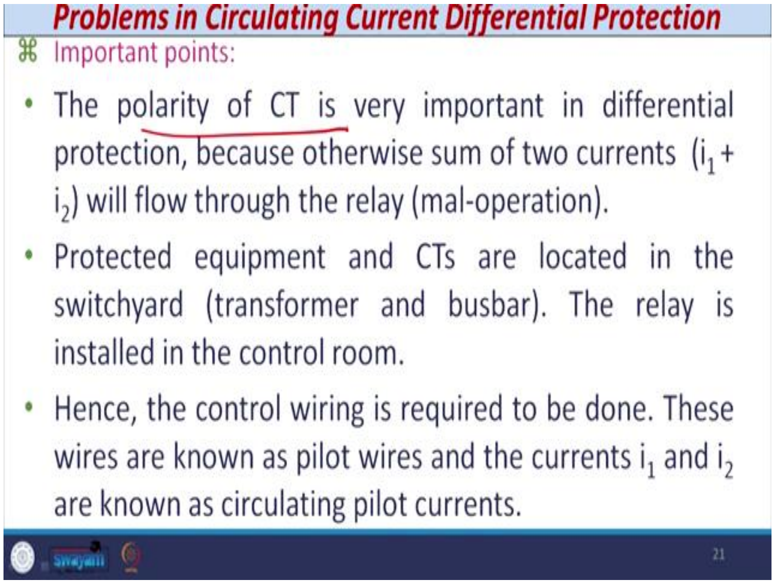

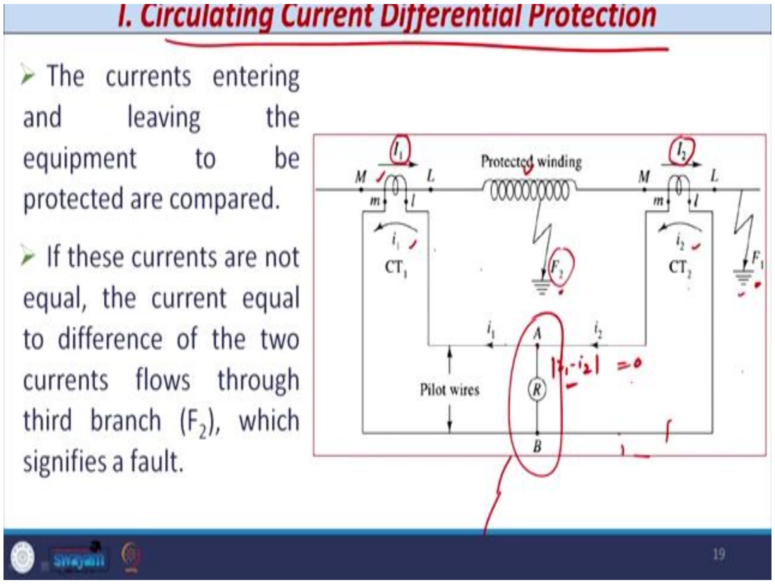

Why this is not possible because of 2 reasons. One, whenever you apply circulating current differential protection scheme, or any differential protection scheme, polarity of the CT, that is very important. If the polarity of CT is not maintain then instead of I1 minus I2 differential current that flows through the relay, the addition of these 2 current I1 plus I2 flows. And hence relay will operate our mal operate in normal or external fault condition. So, first point that is the polarity of the CT that is very important.

The second important point, that is the, we know that the equipment to be protected here that is transformer. So, transformer and the CT both are located in the switchyard. Whereas the protective device that is the differential relay that is located in the control room. So, this CT and the protected winding transformer, both are in the switchyard, whereas the relay that is located in the, or installed in the control panel or control room.

So, you need to run the wires from CT secondary to this point. And here again from the CT secondary to pointy A. These wires are, that is going to carry the current small i1 and small i2, that is this CT secondary current. So, these wires are known as pilot wires and whatever current that flows through this wires that is known as the pilot currents.

Now, keep in mind this relay that is located at equal potential point that means the, this point left hand side of the CT1 to the point A, secondary side, if voltage drop here and the voltage drop on this side from point A to CT to secondary, if these 2 voltage drop are equal, then we can say that the differential current that is ideally 0.

However, these 2 are not equal. Voltage drops are not equal because the lead length, when you run the CT secondary wires from CT secondary to the relay point. These 2 lead length are not equal. So, voltage drops are not equal, hence this I1 minus I2 current that flows through the relay that is not practically 0.

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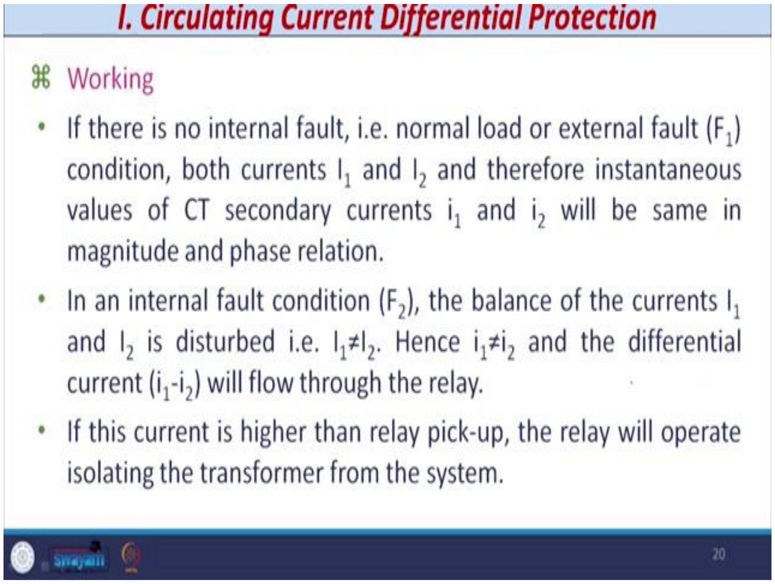

And whenever in practical condition whatever current flows through the relay when there is no internal fault in normal or external fault condition that is known as the spill current. This spill current that is not fault current, but that is normally flows because of the unequal lead lengths on the both side of the relay, because relay is never be located at equi-potential point because of so many reasons.

The third reason that is known as the non-identical CT saturation characteristic, even if we suppose purchase any CT, CT1 and CT2, even from the same manufacturer then also the 2 currents that is the small i1 and i2 are not equal even though the primary 2 currents capital I1 and capital I2 are equal. Hence because of this non-identical CTs saturation characteristic the difference between the I1 and I2 that exists. So I1 minus I2 is not 0 practically.

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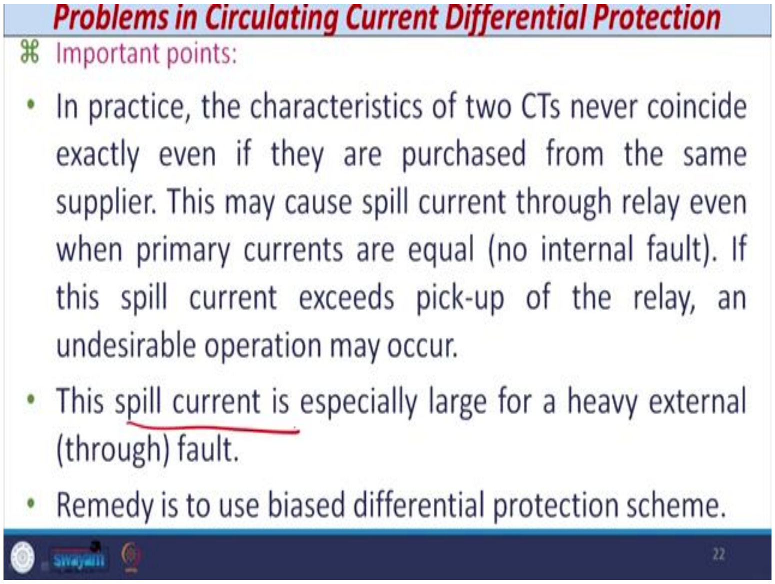

So, because of this, the some current that always flow through the operating coil of the relay and this current that is known as the spill current. Keep in mind the value of the spill current that is very high in case of external fault.

So, whenever we apply such type of protection in actual field, then spill current that is never be avoided. This is mainly because of the non-identical CT saturation characteristic, number 1. The second it is because of the unequal lead lengths. So, spill current is always there and if we wish to avoid this the remedy is we cannot use the circulating current differential protection. Hence, we have to use the another type of protection that is known as the bias differential protection.

So, I stop here and we will continue in the next class. So, before I stop, what we have discussed in this, we have discussed 2 types of fault that is occur in the transformer. One is the incipient faults and the second that is known as the electrical faults or internal faults that occur in the winding and core of the transformer.

Incipient faults are, again, we have to use Buchholz relay for the protection against such type of mechanical fault, it is also known as mechanical fault. Whereas for electrical fault, we have to use differential relay if you go for a power transformer and we have to use some over currently relay, if we apply it for the distribution transformer. So, we will continue in the next class. Thank you.