Power System Protection
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Lecture 41
CT Saturation, Negative Sequence Differential and Restricted Earth Fault Relay

Welcome to NPTEL course on Power System Protection. We are continuing with Transformer Protection.

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In this lecture, we will address on the effect of CT saturation on the differential protection for transformer. How we can apply negative sequence current for the differential relaying application and then beyond differential relay how restricted earth fault relay can be applied for the transformer internal fault protection, which seems to be very sensitive.

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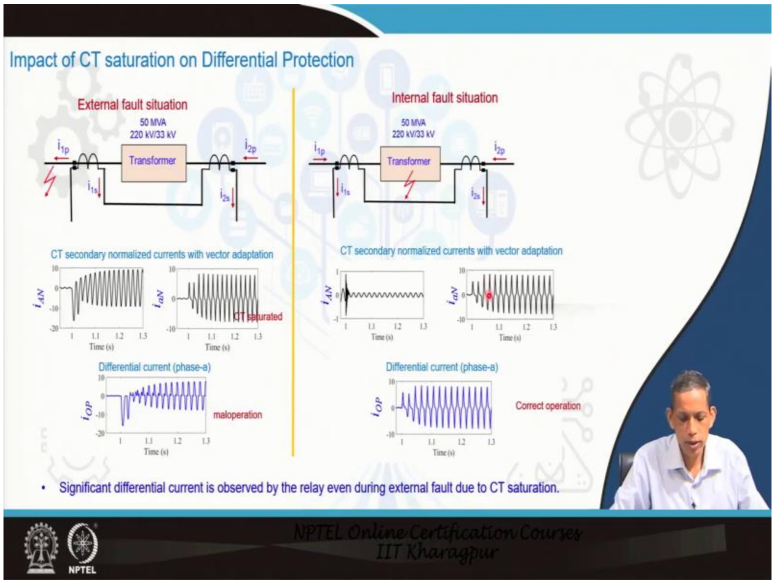

Now, continuing with our transformer differential relay. So, we know with transformer suppose an external fault happens to be there and we have the CT pairs for both the sides high voltage and low voltage side. So, the differential current, so for this external fault the direction of current in the CT connections, the way we have address will be like this and for internal fault the transformer current both the currents will be incoming and the direction of current will be like this as compared to what we see for the external fault.

Now, what happens in case of external fault situation fault is beyond the transformer maybe in the adjacent line or so. So the corresponding transformer current at that time the current which flows transfer may be substantially high and there is chance of CT saturation. As expected the corresponding current in the secondary side, low voltage side, here in this side low voltage side, will be much higher than the high voltage side.

So, here we have shown the issue of CT saturation, current transformer saturation, which we have already learned in our earlier module. So, in that case the corresponding current patterns become different than the expected current that of the primary current, the CT does not faithfully reproduce the primary current.

The saturation amount depends upon different factors residual, faults, CT burden and so that we have learn. Now, let us see here a situation for an external fault the corresponding current patterns in the low voltage side becomes this and assume there is no saturation in the high voltage side and in high voltage side initially some decaying DC as usual and then the current pattern follows a sinusoidal pattern.

Now, from this the differential current as computed through different process like these sequence component in zero sequence component filtering, the corresponding normalization of the current and all these steps are being followed and then we finally differential current i_{OP} using these two currents for the external fault. Then we find that even though it is an external fault the differential current becomes substantially high.

And this will lead to maloperation of the relay unless otherwise it is being addressed. Now, coming to the internal fault situation, yes, is in this case also the current will be, current may be very very high and assuming the similar case then the low-voltage side the current may be let us say substantially high and CT may go for saturation. So with this saturation and then the primary side the high voltage side, that the high voltage side current follows almost the sinusoidal pattern and that is we say that there is a substantial differential current for internal fault, even though CT of one side goes for situation.

So, with this differential current, the differential relay is expected to operate correctly. So, what you conclude from this slide is that if the CT saturates for external fault, then it may lead to maloperation of the differential relay. Note transformer internal fault is a rare event, but external fault like fault in the overall line beyond the transformer may be more frequent in a year or so. So, therefore at that those situations the transformers should not maloperate that is not desirable. Otherwise, it will interfere in the normal operation of the system.

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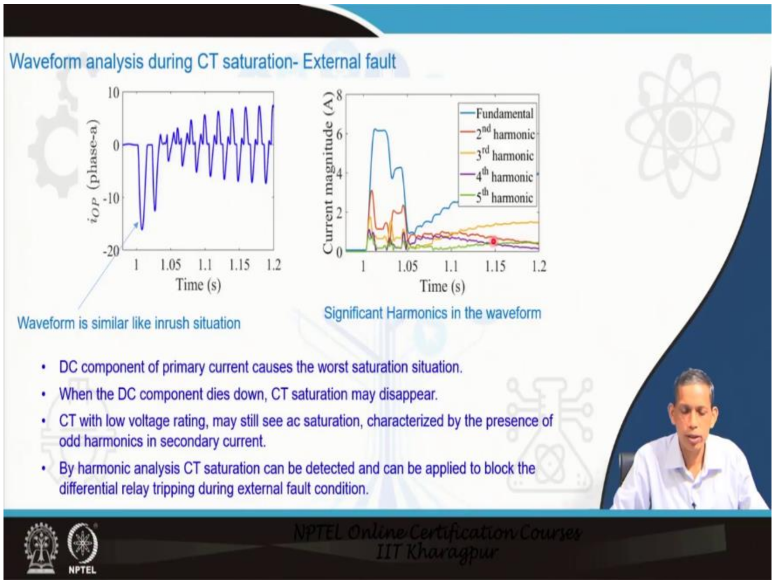

So, how to overcome this issue? So, we will analyse the corresponding current and then we will try to find the solution mechanism to address the CT saturation issue for external fault case. So, we see that the corresponding differential current pattern as in the earlier slide for external fault case you find a pattern like this and if we analyse the corresponding current in terms of the different harmonic components then it shows the patterns that the harmonic currents to be like this.

This is the in the initial period, we have a decaying DC transient like the inrush current defined pattern find inrush current pattern. So, it will be highly second harmonic component and fourth harmonic component will be there and following that because of the CT saturation permanence and all these things the corresponding current patterns will be having lot of odd harmonics are so. So, some of the remarks are DC component of primary current causes worst saturation situation.

When DC component die down CT saturation may disappear, but still the low voltage rating side CT may still have AC situations here means that the corresponding associated with AC current and AC alternative flux also mainly to saturation reason also and which may lead to different odd harmonic components therein.

So, therefore there is a scope that if we can analyse the harmonic components properly, then you can distinguish the corresponding external fault external fault or that either CT saturation issue and thereby we can discriminately CT saturation problem.

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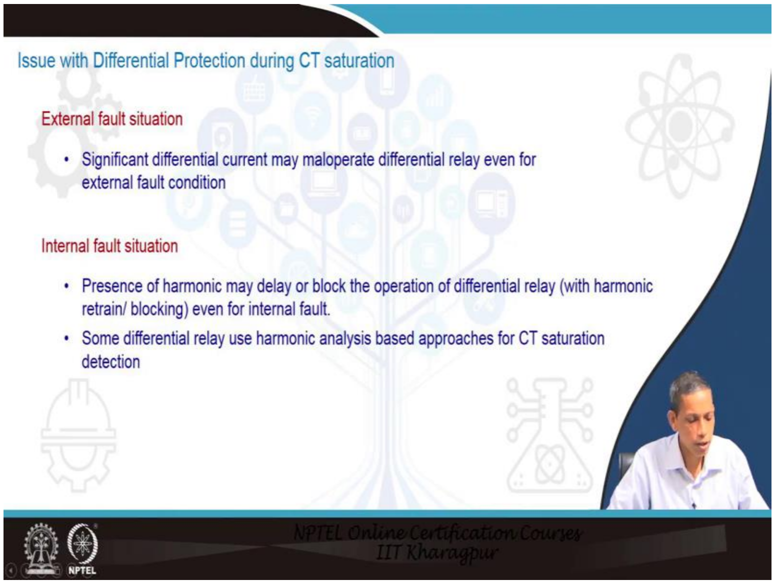

So, what we say that for external fault situations significant differential current may operate differential relay, even for external fault condition. For internal fault situation presence of harmonic may delay or block operation of the differential relay with the harmonic retraining block events, so if we like to apply harmonic component approach therein may delay the corresponding decision process because harmonic components are also used for retraining and blocking for the during the inrush and overexcitation situation.

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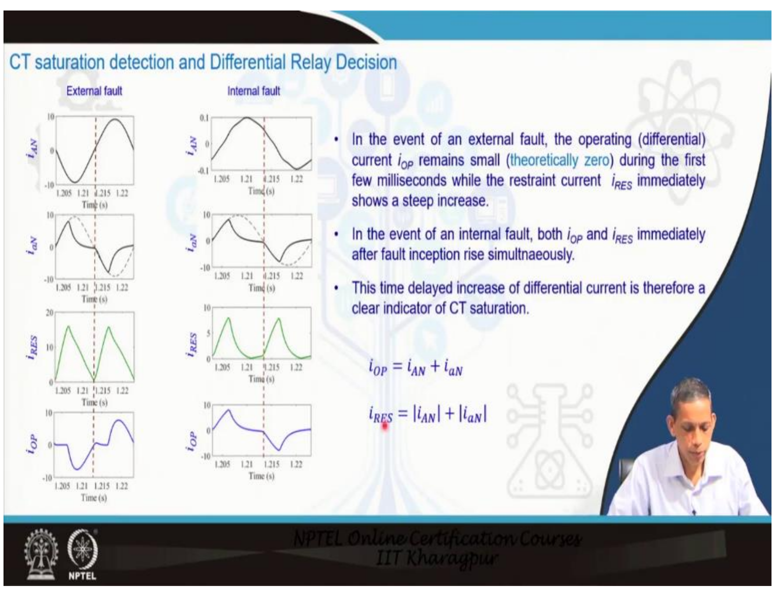

Now, let us move further details. How we can detect CT saturation for the differential relay decision process. So, we have two situation external fault and internal fault what we have already addressed in the earlier slide. So, we have the corresponding current in phase A for external fault and for the internal fault. So, we have, high voltage and the low voltage side which has a CT saturation both for external and internal fault.

Now, what is the finding we see here the restraining current and the operating current, so the operating current $i_{OP} = i_{AN} + i_{aN}$ and the restraining current $|i_{RES}| = |i_{AN}| + |i_{aN}|$are divided by 2 or so that we have different options as you know, so in this case which we see that the conclusion from this restraining current and the operating current patterns from the external and internal fault.

In the event of external fault the operating current remains small during the first few millisecond, you see the operating current for the external fault remains almost negligible and this happens due to that the CT magnetic core does not saturate immediately, it takes some times from milliseconds to a cycle or so, few milliseconds to a cycle or so depends upon the property of the consider this CT.

While the restraint current i_{RES} immediately shows a steep increase because of the magnitude of current is there so you see the steep increase in restraining current for external fault. So, two things the i_{RES} operating current in the initial period does not rise because of the CT core property but the restraining current has a steep rise during this period. In the event of internal fault i_{RES} and i_{OP} both rise simultaneously. So, this is what you observe from the internal fault and from the external fault the corresponding signal analysis.

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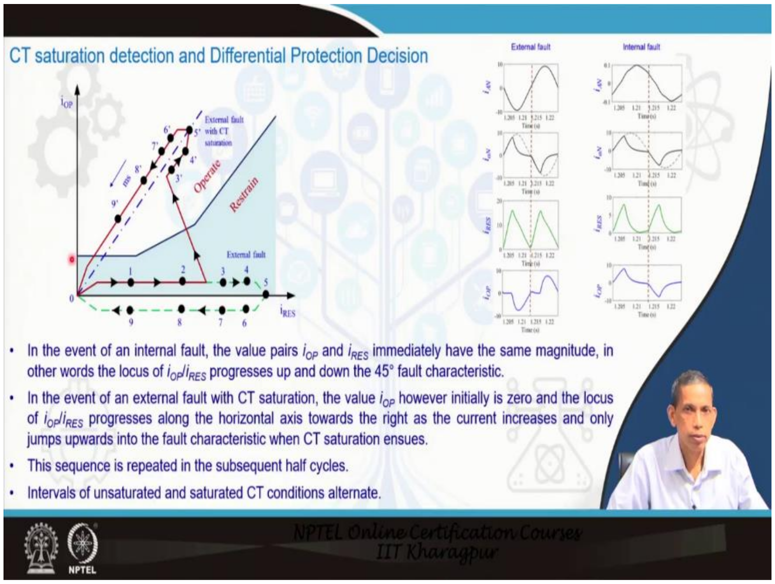

Now, let us go to we applying these concept for and IOP versus IRES plane, that what you see that the corresponding if this dotted line is a 45^{O} line for this plane, then as already enumerated that the i_{OP} and i_{RES} increase simultaneously for internal fault the for internal fault the situation will be that or difference cycles of operation the corresponding operating point will be around this dotted line.

Now, coming to the external fault case what will happen if there will be no saturation for external fault case the differential current the operating current will be say negligible and it will be mostly on the high value of restraining current, so therefore this green portion will be the normal situation of external fault when there is no CT situation.

Now, with CT saturation as already pointed out in the initial period the differential current will be negligible and then high value restraining current will be substantially high. So, therefore in the initial few milliseconds the differential current is negligible, but there is a rise in restraining current afterwards with CT situation the corresponding differential current increases and so the corresponding restraining current, so it will follow a path like this and then around this and this will follow in cyclic manner like this.

So, what you reveal from the that if the CT is does not saturate absolutely no problem that we have already seen in the earlier case where if the CT saturates for external fault it follows a pattern points if we see in this i_{OP} versus i_{RES} plan, then it follows a pattern like this but if is in internal fault even though this CT saturated the corresponding points will be around the this dotted line.

So, that gives us a good scope to discriminate CT saturating from external fault and there by the differential relay can be restrained to operate can be blocked to operate during external fault with CT saturation. So, this is being used in numerical protection system based on this kind of pattern for external fault with CT situation.

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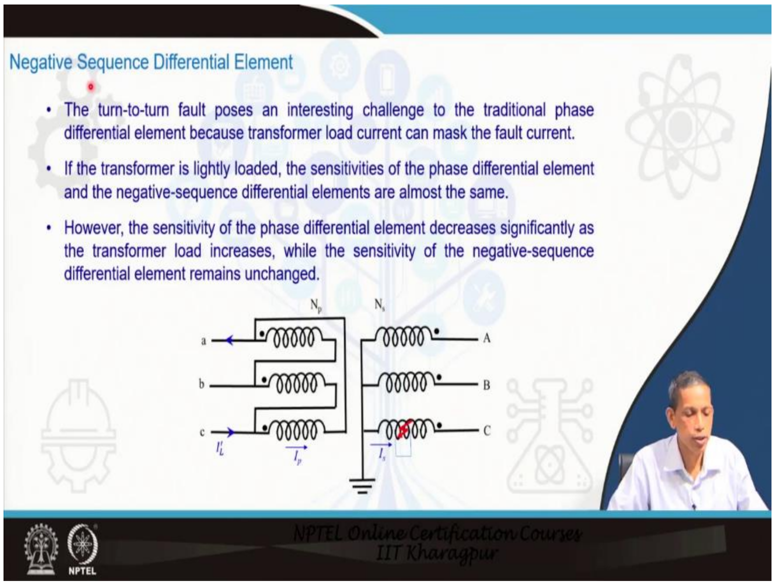

Now, coming to how we can apply other principles in the differential relay also so many manufacturer also provide in differential principle the negative sequence differential element and there being use full in this special cases and in some cases they are very sensitive also like to see how that can be applied and how these negative sequence-based differential principle can be useful. Let us, assume a transformer where we have only faults across few turns.

In that case the amount of circulating current will be localized here and therefore if you see to the supply side the corresponding reflected current for this will be negligible difference. So, that leads to the conventional differential relay phase based differential relay principle will not be useful not be resourceful will not be able to detect such situations when the number of turns involved is small, but this leads to an unbalanced in the current pattern from this 3 phases, which will be noticed during that time.

So, these unbalanced leads to little amount of negative sequence current and that little negative sequence current how that can be captured and useful that will like to see. Note in normal operation of the transformer the power transformer operation almost with balanced. So, therefore there will be negligible negative sequence current but in case of such a situation if the negative sequence current is identified properly, then we can use that for the turn to turn fault also.

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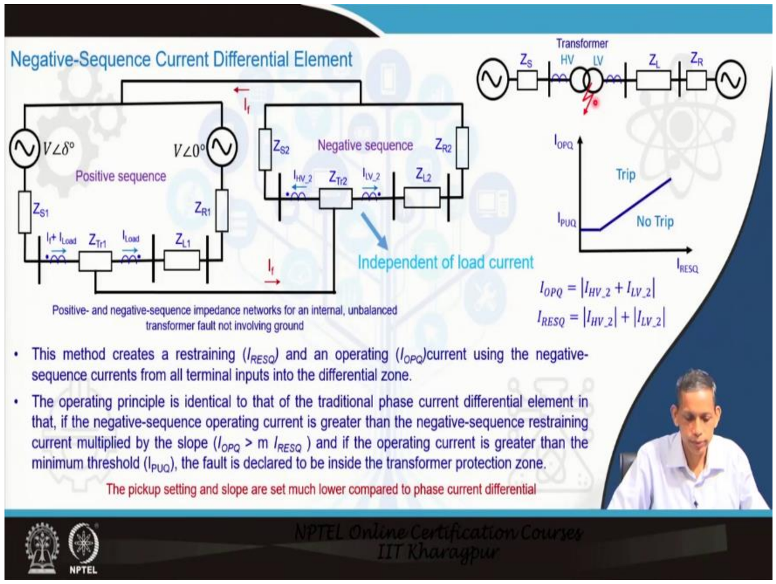

Now, let us try to analyse for a system like this. So we here transformer feeding to a transmission line and then to the grid and so. So, this is Z_L for the transmission line impedance Z_R are for the grid side pass perspective and then source and some generators source in the this side. So, we have high voltage left hand side and low voltage right hand side that of the transformer. And let us say an internal fault associated with few terms in the transformer happens to be there.

Then how we can extend this idea to the differential relay principle using a negative sequence current that we like to see. Now, let us for clarity if fault not involving ground happens to be there and that creates an unbalanced fault. So, in that kind of situation so only positive and negative sequence current will be there, there will be no zero sequence current. So, therefore we have positive sequence diagram and we have negative sequence diagram and then we have the connective in they will connected in parallel for this kind of unbalanced situation.

Now, what happens in this case as we have enumerated the situation the corresponding unbalance amount is very small. So, that leads to suggestion of the corresponding negative sequence current is also small and this is due to the associated impedance of the negative sequence path. Normally in positive sequence component there will be load current will be flowing.

So, to this load current if fault current which goes through to the negative sequence path will be superimposed in this CT's that we supplied for this and then this load current is flowing like this. So, that leads that in the phase component of current which is having a two components here positive sequence and negative sequence but note that the negative sequence component is small in this case.

So, therefore positive sequence component that is nothing but the load component is currently predominant. And that is the reason the normal differential relay using the phase components of current will be unable to detect such a situation. Now, the issue for that perspective so what we do we consider negative sequence based approach where the corresponding operating current Q stands for the negative sequence part equals to the high voltage current and the low voltage current both, 2 refers to negative sequence current.

Similar to that the restraining current in the Q stand for negative sequence based current and both magnitude this or you can take some factor of divide by 2 or so. So, this leads the corresponding characteristics becomes I_{OPQ} and I_{RESQ} in the negative sequence current based approach and this is trip region and this the no trip region with certain slope and we have a pickup current level I_{PUQ} in this perspective.

So, these operational perspective this is similar to the normal phase base differential relay only that we are expecting the negative sequence current and then trying to fit into this particular characteristics similar to the differential relay phase based differential characteristics and check whether it falls into trip region or no trip region. And if the i_{OP} is greater than I_{RESQ}, m stands for the slope of this line and then it is greater than the I_{PUQ} then it will be trip decision otherwise no trip decision.

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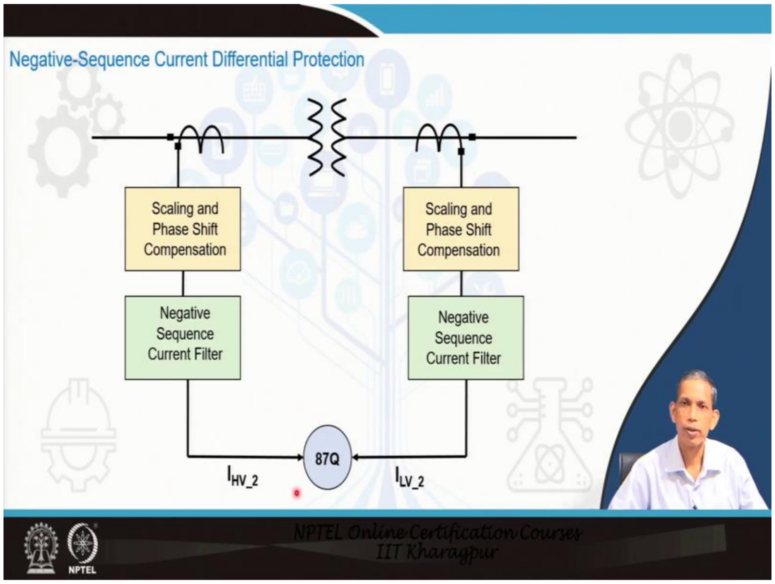

So, in overall such a negative sequence phase you consider a scheme can be summarized to like this from CT signals from the three phases will scale scaling phase shifting both the sides zero sequence eliminations and all these things whatever you carry out. In addition to that will extract the negative sequence current from the low voltage side and from the high voltage side and this negative sequence currents will be now coming for the comparison perspective.

So, that is 87 stands for this differential think Q stand for the negative sequence here so that the 87Q elements will do the business for decision of trip or no trip. And this one is very useful in case of sensitive to inter turn fault also in general. Note that for a fault involving so many terms are fault involving ground and so the amount of differential current becomes in the phase base relays will be significant and the normal the differential relay functioning faithfully correctly, but for this special kind of occasions and all these things the negative sequence can supplement the conventional phase based differential relay principles.

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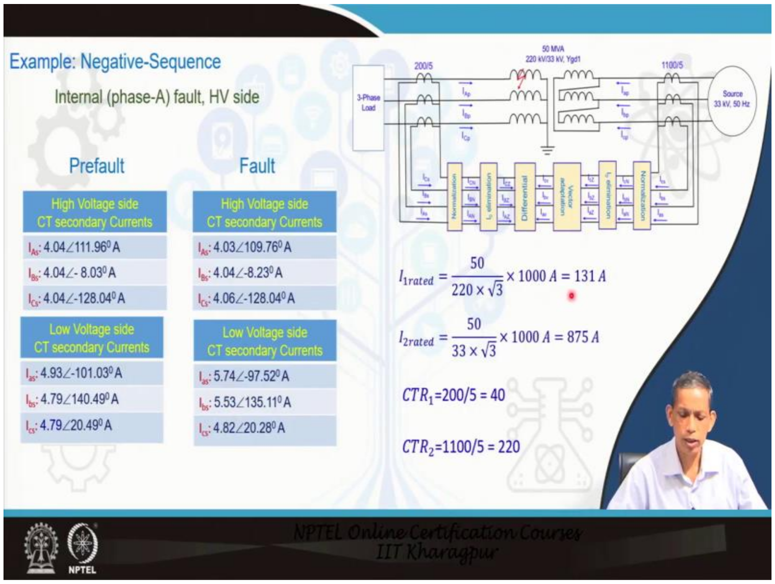

Let us, go to an example. So, we have same earlier transformer of 50 MVA, 33/220 kV transformer. So, we have source this side and load this side and then negative sequence based relay I am said testing and assume that internal fault that we have consider which leads very small amount of unbalance in the system pre fault condition currents are like this, both all-around 4 ampere and like that here for the high voltage side and 4.9, 4.7 4.7 the low voltage side and during fault we now notice that corresponding high voltage side the currents are again remains to be around 4 ampere kind of thing so that is this fault has very less impact on the loading condition of the system.

But now very little change in the low voltage side current which is the supplier side here and these, however it seems clearly the amount of unbalance is very small. So, we have already known that the rated current or the nominal current of the transformer in the high voltage side low voltage side and the CT ratio consider for the high voltage and low voltage side perspective that we have only taken 40 and the 220 CT ratio one and two side.

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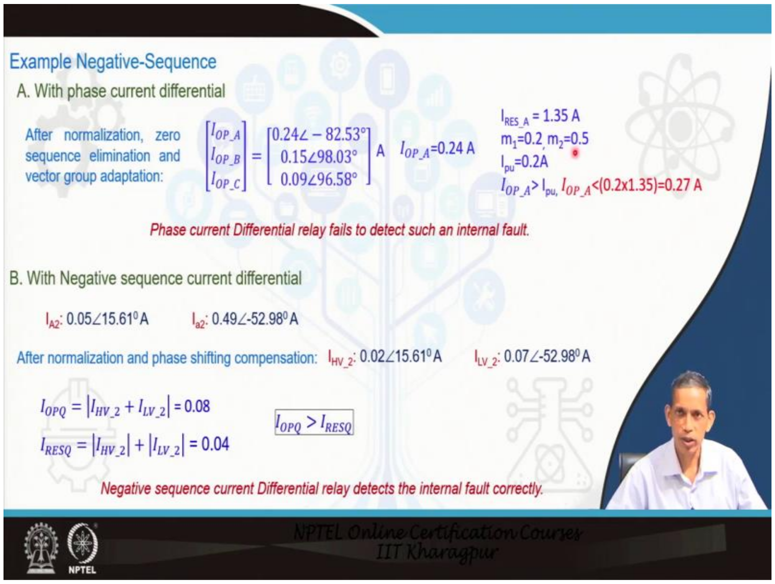

Now, what happens that given the data sets what you have say after the normalizations zero sequence elimination vector group adaptation. So, the corresponding phase A, phase B, phase C currents are there and the fault in phases so therefore associated current in phase A is more and we expect that this would go for the trip business for the phase based relay so we say that I_{OP_A} is 0.24 that we are taking now I_{RES} during that time for phase A is 1.35.

Note here this is significant m1 0.2, m2 0.5 this slope for the percentage wise differential relay phase based relay and I pick up 0.2 ampere after the normalization in so. So, then what you see I_{OP_A} is greater than I_{PU}, true. But if we check I_{OP_A}<(0.2x1.35)=0.27 A. So, this will lead to the corresponding point below the characteristics core and therefore the normal phase based relay will be unable to detect the fault in this case.

Now, for the same case, we will see how this will be seen through the negative sequence based current differential K. So, after processing the corresponding things and capturing the negative sequence from both the sides high voltage and the low voltage side, 2 stands for the negative sequence current capital, A for the high voltage side and, a for low voltage side. So, we got the corresponding values of the negative sequence current and after the corresponding phase shifting and normalization with the, because of the negative sequence current so it will be -jθ formulation.

So, we got the corresponding current 0.02 and here 0.07 so I_{OP} becomes 0.08 and I_{RES} becomes 0.04, you see here the I_{OP} is twice of the I_{RES}, so even if we take the corresponding slope to be 0.2

or so I_{OP} will be greater than I_{RES} current and here so therefore m into I_{RES} will be also valid in this case. And that is the reason the negative sequence will be able to capture this, such a situation where the fault is associated with little amount of unbalance in the system.

So, that leads that the sensitivity of the relay is improved by incorporating negative sequence differential relay. But note that the negative sequence relay, the most of the time the positive sequence, the corresponding phase base differential relay will be good enough, but in case of such a situation a negative sequence based approach can supplement the differential relay principle peacefully.

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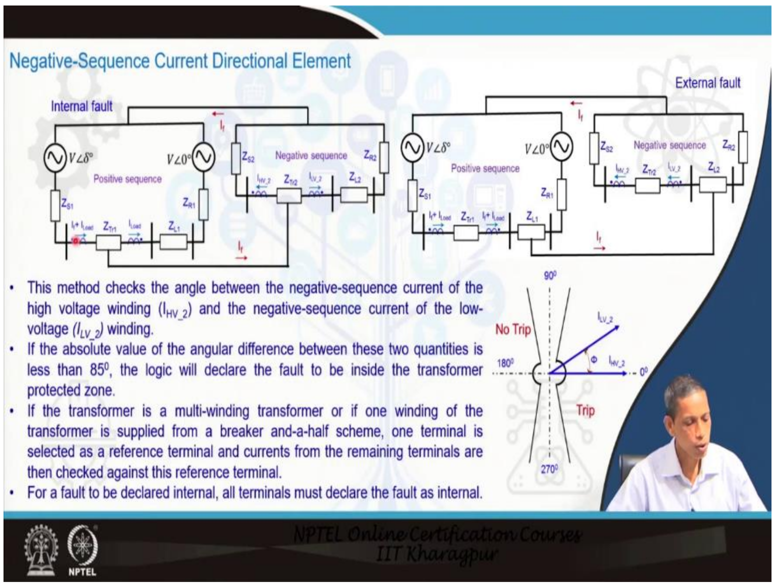

Then another approach the negative sequence based approach and that is based on directional principle. Now, how this principle is there just have a look on this. So, we have the same system and same unbalanced situation of these for not involving ground and we have positive sequence diagram negative sequence diagram and so these for internal fault for external fault positive sequence diagram and negative sequence diagram.

Let us, analyse see the direction of current through the CT's for the internal fault case. So, internal fault the transformer, so we are putting connection diagram like this to the transformer case. So, here corresponding current pattern see here like this like this for the load pattern and the fault current pattern like this. So, here the corresponding fault current will be divided into two it goes to the left hand side and do it right hand side.

Now, for an external fault case which is beyond the transformer that is the, in the line let us say. So, these about that Z_{L2} negative sequence component and Z_{L1} positive sequence this one. So, in that case the corresponding fault current connection will be from here to here and then that fault current will be passing through this.

So, therefore in the positive sequence current pattern will be similar to that and however the negative sequence current if you see this pattern here for this perspective so both will be having it in one direction from this perspective from here it goes against that will be current going through this and then coming to this perspective.

So, that means that if you see this pattern of current here there in the flow opposite to each other and that leads our for internal fault case as you have seen in the earlier example that adds the corresponding current and makes the corresponding negative sequence current to be significant here if they are in the same direction so therefore the corresponding differential current becomes insignificant in that kind of thing.

But note that in this case because the negative sequence current we are analysing if we take the corresponding high voltage negative sequence current to be reference that this current will be almost will be in phase with this for internal fault case and here in this case the with respect to the high voltage because there in the same direction so we can that and with the CT connections, they will be in opposite one.

So, there by the corresponding current patterns will be out of phase almost 180^O for external fault case and then least to a situation if we take the reference to the high will voltage one with respect to that the corresponding low voltage for internal per second will be having a substantial small angle and these small angle due to the non-homogeneity or this impedance between positive sequence and negative sequence current.

So, this will select margin we have to keep for that perspective and in case of the external fault situation, the corresponding angle between the high voltage current and the low voltage current ideally, it should be 180^O, but because of the impedance angle, different impedance angle of the negative sequence side and positive sequence side. So will certain region of per second in terms of this.

So, this source that in terms of the phase angle between high voltage and low voltage in negative sequence component of current, now we can decide whether the fault is internal or fault is external. So, this also is a promising technique in terms of application of negative sequence current for differential relay protection perspective.

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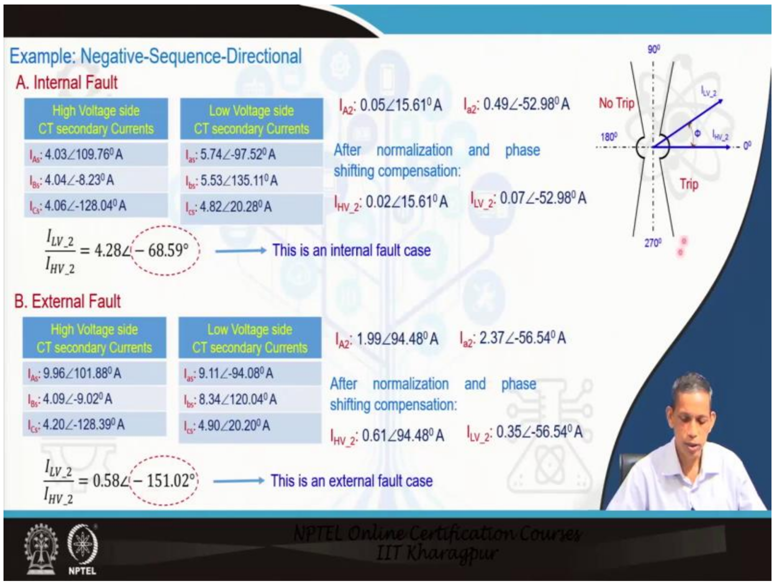

In this for this directionally base same internal fault case is being considered. So, that the low voltage to high voltage because we are talking high voltage a reference, the corresponding angle comes out to be -68.59^{O}. So, it happens to in this region, so this is an external fault case clear for that perspective so you see that here and then if you go for the external fault case another example.

So, then if you see this external fault the corresponding, the high voltage side current and the low voltage side current and then after this normalizations and all these processing the low voltage by high voltage the corresponding angle found out to be -151^{O}. So, that is -151^{O} so it falls in this region. So, this is an external fault case.

So, for external case the negative sequence approach clearly finds it to be external fault and for this internal fault case it finds a smaller angle which falls in this region so that detects the fall as internal. So, that means that the direction information of the negative sequence current between the high voltage negative sequence current and the low voltage negative sequence current can be also indicative of the internal fault and external fault.

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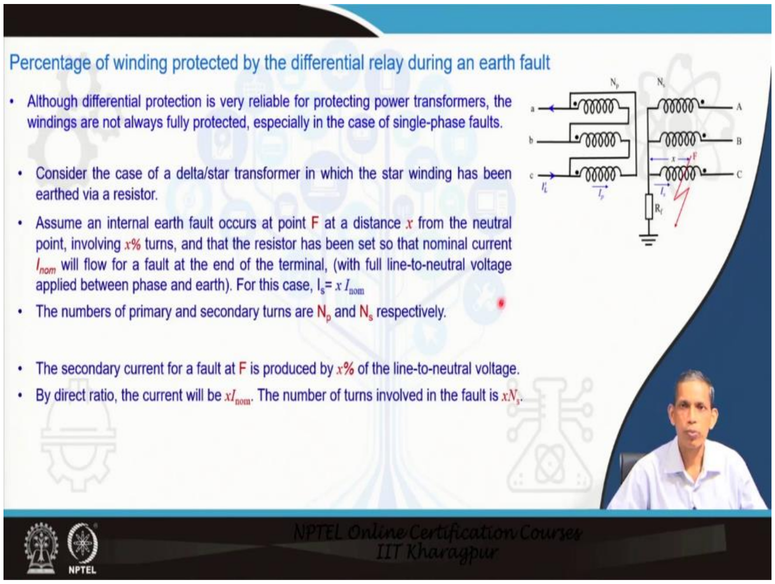

Now, we will go the fault associated with the earth and how we can, what is the corresponding sensitivity of this phase differential relay and how can further improve the corresponding protection of transformer associative earth fault. And note that in most elements the faults are most of the fault are involved with earth. So, we like to see how the corresponding situation happens to be there.

So, let us consider a situation like a delta star transformer with certain star side grounded with R_f, that R_f can be sometimes may be 0 also. So, we have a generic condition we have considered here and let a fault happen at one of the windings, AC winding in this case and that the number of turns involve *x* percent of the total number of turns. So, in this case the corresponding current let us say secondary current flow to be I_S.

Now, in many applications the corresponding R_f, the purpose of this R_f is to restrict the corresponding fault current, fault current limitation, so typically in this case what we have considered, if the corresponding fault happens to be the end of the terminal, then the current which will be flowing through this path will be restricted to the nominal current of the transformer.

Once again, if the fault happens to be the end of the terminal with the rated voltage being applied, then with the presence of this R_f the corresponding current flowing through this path will be the nominal current or the rated current of the transformer. So, that is what in terms of that. Now let us the fault happens to be now from this x percentage of winding now.

So, the voltage associated is also *x* of V secondary and that is the corresponding current associate will also will reduced from the nominal current so therefore in this situation the I_S will be now xI_{nom}. Now, with that we know that the corresponding N_P and N_S primary and the corresponding secondary current voltage as it turns ratio of this and that the corresponding this side currently will follow this turns ratio. So, therefore the fall which is created x percentage and the number of terms involve is xN_S .

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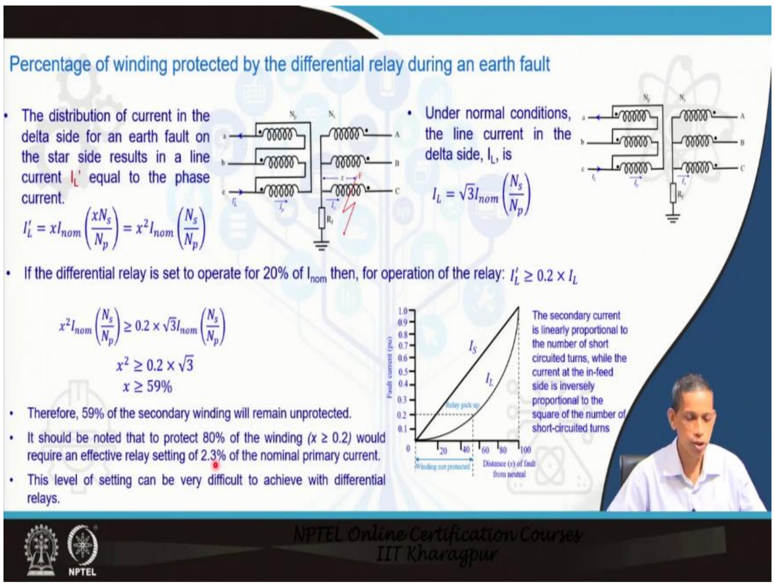

Now, we will go for that analysis if we see this I_L' , the landside current in the delta side, what will be that? So, there we ampere turn balance for this side and this side or this case so ampere turn balance for this becomes, this is associated the corresponding current xI_{nom} for this case and this corresponding number of turns involve see N_P multiplied by total number turn, N_PI_P this side xN_S into the corresponding I_S.

So, therefore xN_SI_S, I_S is xI_{nom} and N_P multiplied by the corresponding I_P. So, that is why I consider two X squared terms come to here, but note that here because this is not a normal balance condition or so and unbalanced situation and fault current is flowing through only here. So, these current for this current in this phase C the corresponding this winding will be having this I_P current which will be maintaining a ratio of this ratio N_S and N_P and this current will be supplied from this phase C.

So, therefore the corresponding and I_P current is nothing but $I_L' = xI_{nom}\left(\frac{xN_S}{N_p}\right) = x^2I_{nom}\left(\frac{N_S}{N_p}\right)$. This will be better clear if you go to the normal situation where we have a balanced current flows in this side and a balanced current flows in this side. So, this I_S and I_P maintain the ratio of N_S upon N_P and the I_L current maintains is having a √3 times these corresponding I_P current.

But that √3 factor will not come here because this is we know here this current is flowing through here. The associated winding is here and that current will be supplied from this side only. So, that is region here we are not finding a √3 factor here and $I_L' = x^2I_{nom}\left(\frac{N_S}{N_p}\right)$.

Now, when we apply these situations to the differential relay, let us see the corresponding m1 slope having 0.2 or 20 percent of the I nominal then how the corresponding relay will see this perspective. Let us, say I_L' should be greater than equals to $0.2I_L$. In that case the corresponding this $x^2I_{nom}N_S$ upon should be greater than equals to 0.2, but the setting will be in terms of this factor that we know, so therefore $\sqrt{3}I_{nom}\left(\frac{N_S}{N_p}\right)$ and that gives us x to be equal to 59 percent.

Now, what this x 59 percent reveals, then the x which we have already pointed out that they fall from this the neutral point and so. So that distance and we have a balance the equate in terms of this. So, that means that the 59 percent of the secondary winding will be remaining unprotected. What do you mean say that when the corresponding fault happens to be closer to the neutral point then the amount of voltage applied will be smaller the amount of current be smaller and that will lead to the differential current to be smaller and smaller.

So, that creates a problem and that is the reason if you have 20 percent slope setting then each reveals that in this kind of environment than 59 percent of the winding will be unprotected if it is involved with the all involved with ground like in phase B and phase A also. Now, that means that this comes out to be a very large figure and that is an issue in the percentage by differential relay using phase current based approach.

So, now if you like to reduce the figure of 59 then let us it should be noted that to protect 80 percent of the winding that means that the x will be 0.2 kind of thing. For that case the corresponding slope should be only 2.3 percent. But then if you go for this slope to be very reduce then security will be compromised.

So that creates problem in terms of that and that is the reason we need alternative arrangement for this kind of situation and what is that we like to see right now. So, one point here that the corresponding I_S the current in this perspective follows in terms of the corresponding distance of x from the fault more amount of voltage. So, corresponding current I_S goes on increasing. But as you can see this I_L form this side the delta side the corresponding turn becomes involved with x square.

So, therefore I_L takes save light this kind of thing and there is what we can say in terms of this that the I_S is linearly proportional to the number of short circuited turns and while the current in the infield side, source side, that becomes square of the number of short circuited turn in case of a star grounded side with certain fault resistance and so. If the fault resistance is 0 or so the corresponding pattern IL become further different.

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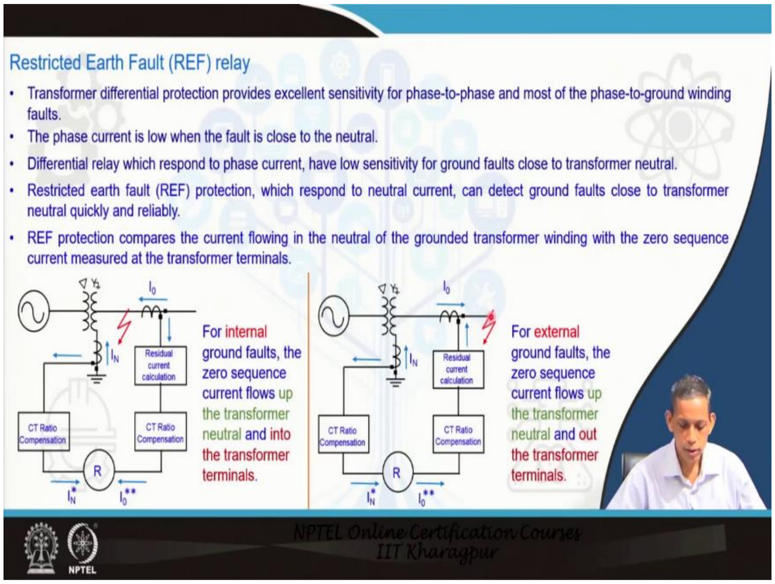

Now, to overcome this solution that the percentage biased relay faces for this earth fault and the fault closer to the neutral point then we apply a technique called restricted earth fault relay. So, what is the principle here we see here let us you can see delta star rounded system and let us say the corresponding source side is delta side as we have discussed earlier and here the neutral you have CT connected to the neutral and then you take this corresponding current to the restricted earth fault relay.

And here CT connected with three phases through which you can compute the zero sequence current and then the residual current is being there with CT ratio compensation and all these things and these two currents the way we have planned to how to compute this corresponding current this neutral current and this current are to be process in this restricted earth fault relay.

Now, what like to see here that this is an internal fault case and if you see here for internal faulty here the corresponding current will grow from the ground to this we will find this path like this and from this side, this will find a path like this.

So, if you see this current from the ground path in the neutral branch the current in the transformer will be upward and from the line side in this transformer set it will be into the transformer and now come to external fault this side in this case path of current for the external fault case this is grounded so from the ground side again, it goes like this and to this one and the CT in the three phase CT is three CT's the corresponding zero sequence current also flow like this.

So, what we see that for this the neutral current ground current also flows off like the earlier case, but in the zero sequence current goes out of the differential current protection arrangement. Here it is be in inward into and it is outward so that the out of the transformer case so that is the discriminate factor for this case.

So, what you can do here for this kind of thing that we can have the corresponding angle between I_N and I_0 in one case in this case they will be aligned and in one case they will be out of the phase also. So, that gives a clear idea that we can discriminate internal fault and external fault note that such an approach gives a very high sensitivity to the relay protection for ground fault involving in star grounded set transformer.

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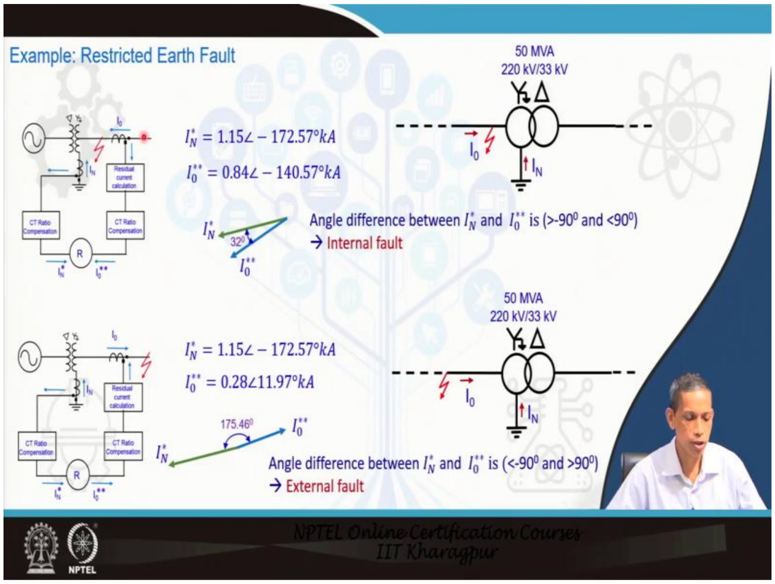

Now, will see through one example how restricted earth fault is the sensitivity of that branches is and how good it is easy to handle such a situation. So, we have transformer as usual that 50MVA transformer, 33/220KV and then consider two have is internal fault case and then we have an external fault case. So, for the internal fault case involving ground and so, here the arrangement we found these corresponding I_N^* this current which is entering to the restricted earth fault relay is $1.15\angle -172.57°$.

And the I0 current from the computed from the three phases current happens to be $0.84\angle -140.57°$, so the angle between this because we have considered the corresponding things, the corresponding CT connection is like this. The angle between I_N and the I_0 connected, the way connected for the differential relay applications, the angle between 32^O for the internal fault case and as already mentioned for external fault case, the corresponding current is going out and in this case with the differential relay arrangement of the computing the zero sequence current through this I_N and I_0 substantially large angle of 175^O or more. So, this is clearly an external fault case.

So, what we see here that these approach or restricted earth fault relay if such the information of internal fault and external fault for the fault involving with ground in this star ground side and its sensitivity is very high as compared to phase base percentage by difference relay which as side has probably associated problem.

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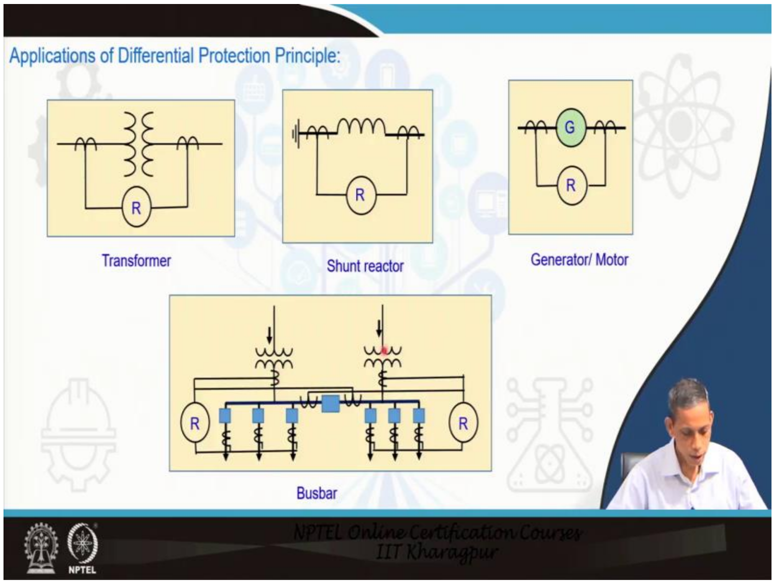

We learned the differential protection for transformer how to connect the CT in star grounded and star side and star side star connections and how to have to we have to ground with both the sides and how to process the corresponding signal for successful applications we learnt also transformer differential protections how to apply negative sequence base approach restricted earth fall how to have the corresponding CT saturation issue also

Those ideas can be for the differential protection can be extended to sound reactor applications can be extended to generator and motor transformer also, busbar protection also, like see here this is a bus and we have this bus coupler. So, we have CT's all the connections these are out going lines feeders to the load side and the incoming lines feeding through to transformers let us say.

So, what is being done here again so this incoming line CT1 here and from this incoming line this CT may feed also this so this is another one. So, they will be added their incoming the outgoing one, two, three from this side. So, this three currents from the outgoing three currents for this relay will be compared with this incoming current this side and differential we can be applied for the busbar protection.

Similarly this side this is one and this side one because this may be feed from this also these two are added, and these are the outgoing currents and they will compared the differential relay can be useful for busbar protection also. In the next module we will see how the busbar can be protected using such principle also.

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In addition to the electrical signal based principle for transformer protections especially differential relay applications and so. There are other gas relays and so particularly Buchholz relay is of significance which it takes the position between the conservator tank at the transformed tank and whenever some incipient fault or minor fault happens to be there.

Some short circuit lamination insulation, core bolt insulation and so faulty joints or any other internal faults the corresponding gas formation in the transformer oil goes to the upward tank conservation tank and to this basis this relay position, which is operate based on the gas formation in the inside the transformer tank and so that can be also is can be useful for the transformer protections, trip decision and so.

There are numerous other relays also over current relay and other former relays are also available for the transformer successful operation the transformer for internal fault. And however, we learned in this module on particularly emphasizing on the differential relay applications to transformer protection percentage biased.

Then we expand its limitations we extend the idea the differential protection using negative sequence based relay and then also the restricted earth fault relay and so. And we discussed about how to retrain the corresponding differential relay during in inrush and overexcitation and so. Thank you.