Power System Protection
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Lecture – 38
Differential Relay

Welcome to NPTEL course on Power System Protection. We are continuing with transformer protection, we will go to details on differential relaying principle.

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In this lecture we will address on percentage biased differential protection philosophy and then we will proceed how a numerical relay does with different steps. We will have the initial portion on that. First step will be on normalization current and the other steps we will elaborate more on subsequent lectures.

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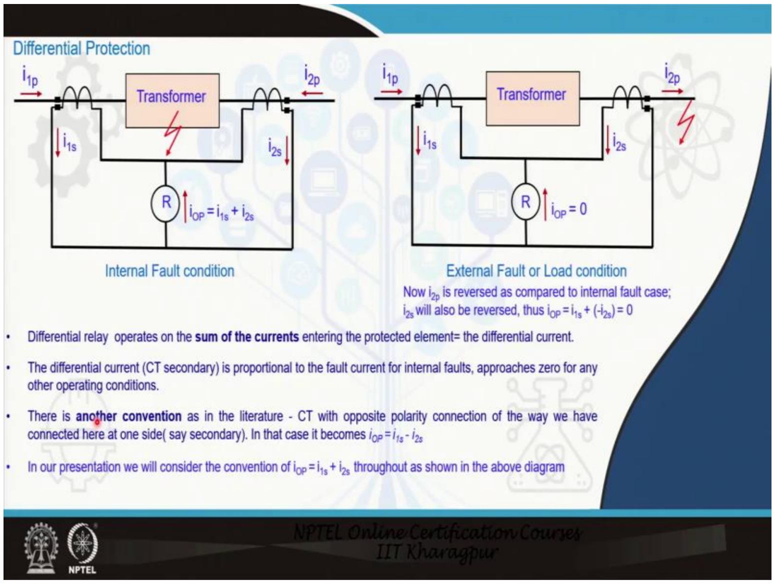

So, in the last lecture, we discussed on the differential protection and how the corresponding differential current is being processed in the protection scheme. So, if you remember, if this is the transformer, so we have CT's in the primary side, here on the secondary side also. So, we have i_{1p} the line current flowing in the primary side and i_{2p} the line current flowing in the secondary side.

We have CT connection and then in the secondary side of the transformer we have i_{2s} and we have in the primary side the i_{1s}, this current flows in the relay. Now, note how the corresponding CT is being connected that is the CT polarity in both the sides that matters what will be the corresponding current through this differential branch.

So, this R stands for relay, through the relay how much current will be sense that depends upon essentially the corresponding polarity connections at the two ends of the transformer. Now, in this one if you remember, for an internal fault the corresponding current directions into the transformer being taken as the convectional current philosophy in the last lecture also.

So, the corresponding differential current, otherwise called also the operating current that becomes equals to i_{1s} here this side and i_{2s} this side that becomes, so operating current becomes equals to

$$i_{OP} = i_{1s} + i_{2s}$$

For an internal fault both i_{1p} and i_{2p} will be this directions and CT polarity connections in this fashion then the direction of current here, if this is entering here, so this should leave here so that is why the direction of current i_{2s} this is entering here so at this terminal this will lead here so direction of i_{1s} is this. So, with this philosophy this result i_{op} equals to i_{1s} plus i_{2s}.

Now, come to a situation when external fault or loading condition or so then what happens here the direction of current is flowing away from the transformer in the secondary side. So, therefore with the same polarity of connection we can say that what we have seen in the earlier one. Then what will happen in this case the current being reversed as compared to that the corresponding current in the CT also reversed, so that is why the direction of that i_{2s} will be in this way.

The primary current remain in same incoming current here in this direction with this CT polarity the corresponding current direction will be leaving to this terminal, so i_{1s} remain same as earlier case. That results in the corresponding i_{1s} and this corresponding i_{2s}, so i_{1s} flows here and i_{2s} leaves here, so therefore the differential current becomes equals to i_{1s} plus $-i_{2s}$ and if this i_{1s} and i_{2s} are same because assuming the correct value of the CT's available then this current will be ideally 0.

So, this is what the corresponding philosophy being used in the for the transformer differential current perspective. So, we see the differential relay operates on the sum of the currents entering to the protected element and that we term as a differential current. The differential current at the CT secondary level is proportional to the fault current for the internal faults and approaches zero for any other operating conditions.

So, for this internal fault let us say x amount of current flows here, so then i_{1p} and i_{2p}, i_{1p} plus i_{2p} will be x and then in the similar issue so this i_{1s} and i_{2s} are proportional to i_{1p} and i_{2p}, so therefore the corresponding i_{op} will be proportional to the x amount of current depending upon the CT ratio and so. So, that is what we say that the operating current here for the internal fault i_{1s} plus i_{2s} is proportional to the amount of fault current in the internal fault current in the transformer.

Note, in literature we will find while studying that there is another convention also used you will find in the literature, if the CT polarity change here, then this one side one is one side of the CT polarity change then what happens that the corresponding sin convection which we have used i_{1s} plus i_{2s} that becomes equals to i_{1s} minus i_{2s}.

So, that only difference you will find, so many books and literature go for that kind of approach but that does not conflict to the protection philosophy in general. However, the approach which we have described here will follow throughout that is i operating becomes equals to i_{1s} plus i_{2s}.

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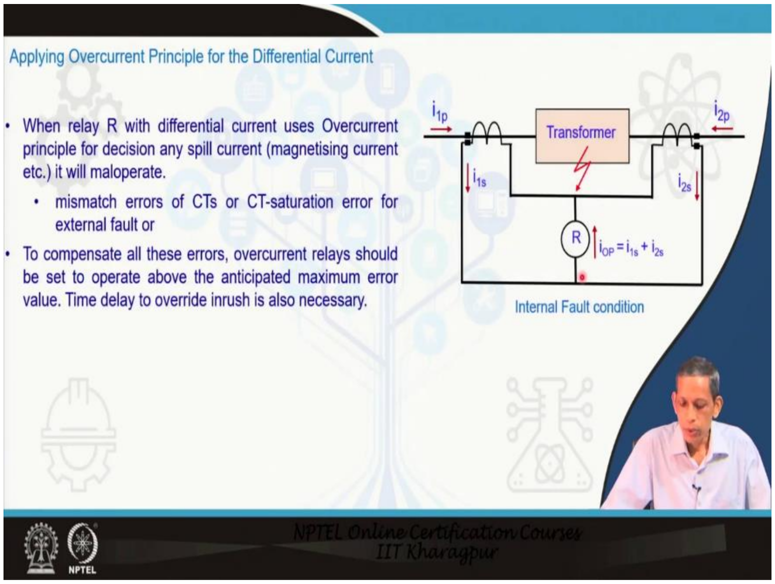

Now, we know that for any internal fault the i_{1s}, and i_{2s} will be summation of this, will be proportional to internal fault. That means that the differential current or the operating current will be significantly high for an internal fault in this arrangement. So, if simply adjust the amount of current in this branch then the corresponding protection can identify, protection scheme can identify that this is an internal fault.

For any external fault this current becomes i_{1s} plus - i_{2s} that becomes close to zero so therefore the corresponding current through this differential branch will be significantly low or ideally 0. So, by an overcurrent principle we can discriminate whether the fault is internal to the transformer or external or a normal loading condition or so.

So, that is why we can think of an overcurrent principle for this differential relay applications with available currents from the CT as shown here and the connection becomes as we have followed in this diagram. Now, however the problem with that there are numerous problems applying overcurrent principle in this for the differential current branch.

Number one, transformer has magnetizing current, so if that flows only primary side will not flow in the secondary side that means that is an additional current to the transformer in the primary side so that current will be additional current and that will flow, so that is the spill current flowing through the differential branch.

In addition to that if any CT ratio mismatch happens to be there which we have already calculated in the earlier lecture, then what happens that even though there is no fault or for external fault situation the corresponding differential current will be again there because of the mismatch in CT.

So, these are not internal fault situation, but still differential current will be flowing and that will be significant if the fault happens to be external and very large amount of current in case of a CT ratio mismatch. We know during the CT performance study that CT may saturate and thereby what will happen the corresponding current may be substantially low.

So, for an external fault if any of the CT's will saturate so even though it is external fault at time also differential current will flow. So, therefore the overcurrent relay will be unable to discriminate whether it is internal fault or external fault in those kind of situation. Therefore if we think about applying a simple overcurrent relaying principle here that may find limitation in overall performance while protecting a transformer.

If we try to compensate all these errors then the pickup current which will fix for the overcurrent relaying will be very large and therefore the pickup current becomes very large then the dependability issue will be compromise in general. So, in alternate ways are being sort and we will go on that perspective.

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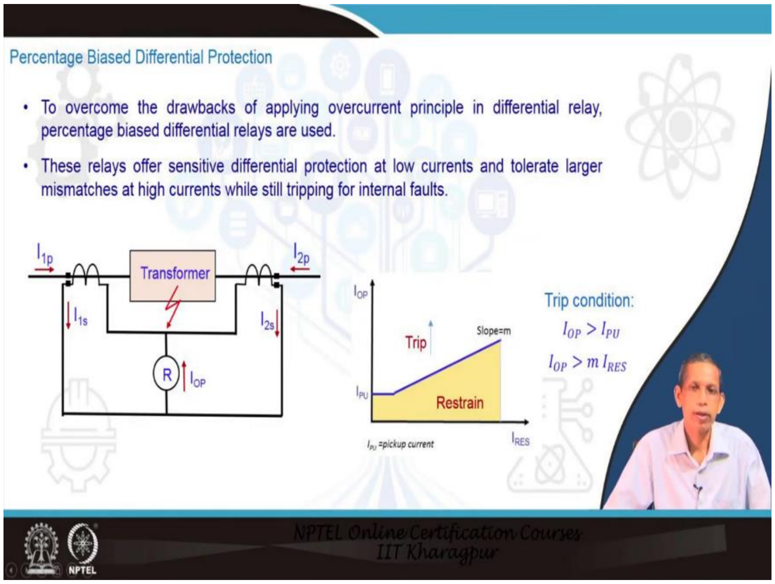

The solution to that if you see the different literatures and available relaying principle in this most of the relays use percentage biased differential protection in a numerical platform. So, these relays offers sensitive differential protections even at low currents and tolerate larger mismatch at high currents also during CT saturations or another like magnetic inrush and over excitation situations issues also which the overcurrent relay find challenges.

So, what is being done here, this kind of connections and all these things we have this relay characteristic very basic one we are going for then we will go for the further details on this. That the differential current versus the corresponding restraining current. This restraining current is nothing but related to more current through these two CT's then the corresponding oppositions to the operating current will be more and more.

The philosophy behind this is that whenever the corresponding through current, external fault current the amount of current becomes much higher and then let us say one case, one situation we consider CT ratio mismatch. If the CT ratio mismatch is there and for the external fault the current becomes very large, because of the CT ratio mismatch the amount of current which will be flowing through this branch is also larger. So, that is not an internal fault situation, to overcome that problem, it means that for large current, external current or large current through these CT's the restrain should be more also. That is what in this protection philosophy it is being provided that if you have large current in this CT's then the restrains should be more and there we can say that the relay can perform better way.

So, what we have shown here that we have a slope here and this slope maintains that approach what we talk about the restrain. What is the restrain current and how much the corresponding slopes should be taken care and all these things, rest of the details will have in the next subsequent slides. Note here we have some spill current always in this branch like magnetizing current and so or any CT ratio mismatch and that amount.

So, therefore we have a minimum pickup current, minimum current setting that we call the pickup current setting. So, in this environment situation the trip condition for the differential relay will be

$$I_{OP} > I_{PU}$$

$$I_{OP} > mI_{RES}$$

Whenever the corresponding operating current is greater than this threshold value above this, it is trip region otherwise it restrains, it remains silent.

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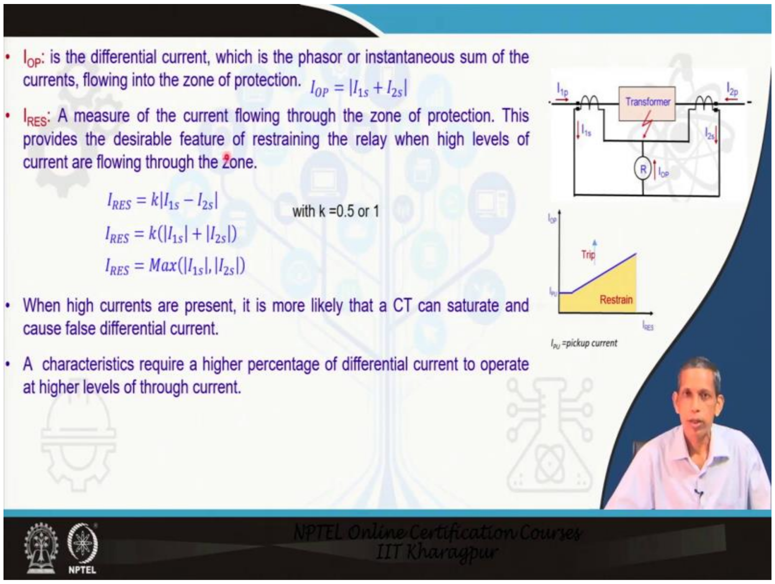

Now, we will elaborate more on this perspective what are this I_{OP}, what the restrain current and so on the percentage by differential relay principle. So, this I operating here is that differential current, so this branch or numerically the corresponding i_{1s} plus i_{2s} what we have already elaborated on.

So, is the differential current, which is the phasor or instantaneous value, it can be both, some relays, mainly most of the relays phasor values and many relays they exploit the advantage of high speed protection using instantaneous values also. So, flowing into the zone of protections, so flowing into the zone of protection is the transformer here and so here whatever current flows into that with that considerations the operating current or the differential current is I_{1s} plus I_{2s} which we have already discussed and this principle we will follow in our approach.

The I_{RES} current is in this percentage relay biased characteristic, is the measure of the current flowing through the zone of protection, it is a measure of the current flowing through the zone. We mentioned that the big challenge CT ratio mismatch, CT saturation and so. So, for that we say that whatever current is flowing through this zone, so it is a measure of that, which one, the restrain current. This provides the desirable feature for restraining the relay, for not allowing the relay to operate when high levels of current flowing through the zone.

So, the relay search differential protection is vulnerable as we have mentioned earlier that whenever a fault happens to be external to that and because of some CT ratio mismatch or so the spill current or the differential current will be significant and to avoid that the restraining current approach is provided but we say that the more the corresponding through current in both the CT's the more restrain is required so that the relay does not operate for that external fault or any other conditions.

So, for this if you see the literature, manufacturers provide generally three approaches for computing the I_{RES},

$$I_{RES} = k|I_{1s} - I_{2s}|;$$

$$I_{RES} = k(|I_{1s}| + |I_{2s}|);$$

$$I_{RES} = Max(|I_{1s}|, |I_{2s}|)$$

with k = 0.5 or 1 in these relations. Most of the relays use k = 0.5, k 0.5 is a very popular value. When high currents are present it is more likely that the CT may also saturate and then a false differential current may flow which we have already mentioned.

So, this may lead to operating or the relay on wanted mal operation. So, to avoid that when the corresponding current happens to be large then this happens to be there. Therefore we can say that the mechanism has to say that take care that perspective and all these things, so that is what we say here.

So, we essentially require a characteristics a higher percentage of differential current to operate a higher level of through current. It means that when through current is external, through current is large, so essentially we require a higher differential current and that is the reason we keep a slope here for this region and that mitigates or provides a way to overcome this problem.

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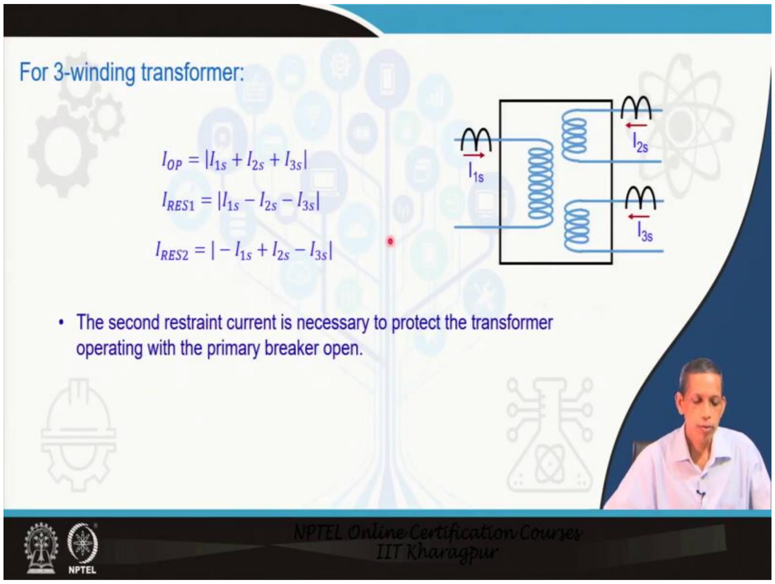

Now, that we discusses is of two-winding transformer, three-winding transformer like a delta winding is maybe a third winding option and so in many applications in high voltage system and so power transformer. So, in that case I_{1s} entering, I_{2s} entering, and the third winding I_{3s} entering, so all three currents are entering to the zones that is what the philosophy we are considering in our approach. So, in that case the operating current is

$$I_{OP} = |I_{1s} + I_{2s} + I_{3s}|$$

and the restraining current is given by

$$I_{RES1} = |I_{1s} - I_{2s} - I_{3s}|$$

Now we are having another restraining that is required in case the corresponding primary side breaker is open given by

$$I_{RES2} = |-I_{1s} + I_{2s} - I_{3s}|$$

And we are feeding only from the secondary side, so that means we can say that the corresponding I_{1s} may reverse from that perspective, so that is why the second restrain current is necessary to protect the transformer operating when the primary is open, one side breaker is open in that perspective and all these things. So, these are the different restraining and operating currents being considered for a two-winding and three-winding transformers to have the required percentage biased settings.

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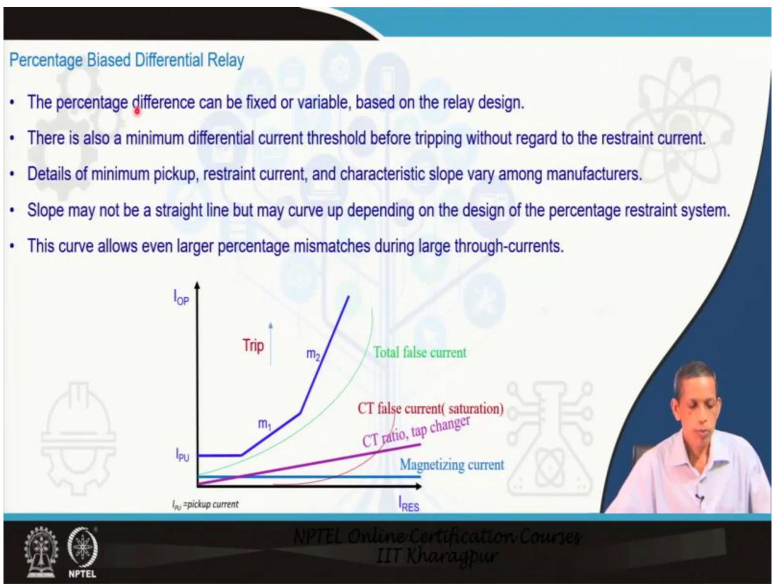

Now, having the more details on the percentage biased differential relay. So, we are going more details in to that and in the subsequent lectures also we will clarify on different perspective and issues related to differential relay operation with using percentage biased principle. Note, the percentage is differential, characteristic can be fixed or variable, based on the relay design that flexibility they are in today's numerical relaying principle. There is also a minimum differential current threshold before tripping without regard to the restraint current, so that is a check that there must be at least minimum differential current, you can think about this I_{PU} current and so. Details of minimum pickup current, restraint current, characteristic slope vary among manufacturers.

So, here if we see the characteristics, we have pickup current, and the different slopes and all these things so that whereas the manufacturers. Slope may not be one slope as we have earlier shown with one slope as earlier, slope can be two slopes m_1 and m_2, now we have different slope here, the reason behind already we mentioned that during high current level the chance of the differential current may be much more having larger value of the differential current is due to CT ratio issues or the more prominent possibility of CT saturation issue.

So, these curves allow the percentage mismatch during large currents also, it is not necessary some relay use a curve for this perspective also instead of two slopes of m_1 and m_2. Now, note that how to decide this m_1 and m_2 or this characteristic above which is a trip and below which it is the restrain region.

So, for this let us start from the very basic one the magnetizing current, so we have this magnetizing current two percent or so for a transformer, we say CT ratio mismatch, let us consider CT ratio mismatch, it means that both current through the two CT's means the corresponding differential current becomes more so that is why CT ratio mismatch leads to the corresponding differential current, unwanted differential current more and more for the larger value of through current, through current larger means it is restraining current also becomes larger, so that is why the line becomes like this.

In addition to that the tap changing transformer, most of the transformers in power transformer they have the tap changers, so that tap changers where then the turns ratio of the transformer none $N_1:N_2$ change and then again the corresponding differential current will be more prominent.

So, therefore if the corresponding loading condition is higher and higher means restraining current is higher due to its tap changing condition changing that the corresponding differential current may be more and more but that is not an internal fault situation. Furthermore we know CT has limited performance when the current becomes significantly high because of the CT saturation issue.

So, therefore we expect very large false current in the differential branch due to CT saturation perspective and this is the curve like this. Now, when we add all these perspective and so then the total sum of false current that we are seeing in the differential branch may be the green curve like this, so this is about adding all perspective and so.

So, having some margin above this so that the decision can be more secure unwanted tripping can be avoid then a curve like this for the differential percentage by differential relay characteristics. And on that as already mentioned we can many relays put to slopes m_1 and m_2 and this m_2 slope is much higher than this m1, typically m_1 can be 0.2 to 0.3 kind of thing, and m_2 can be much larger as 0.5, or so.

To mention also clearly that the reason behind the larger value of that one go for the more mismatch, more differential current and also CT saturation creates further problem. So, to avoid that kind of things this kind of m_1, m_2 becomes, the m_2 becomes larger than the m_1. Furthermore depending upon situations we will elaborate more on that, this can be also adaptive, this portion can be adaptive sometimes you can make it more and sometimes you can make it higher depending upon to have the required security or dependability a better accurate protection approach and so.

The pickup value is decided, what is the spill current flowing through this because of this CT ratio mismatch, the magnetizing current and so, and this is the minimum current above which the trip options can be triggered and then we say that anything above this curve is trip decision and below this is the restraint option.

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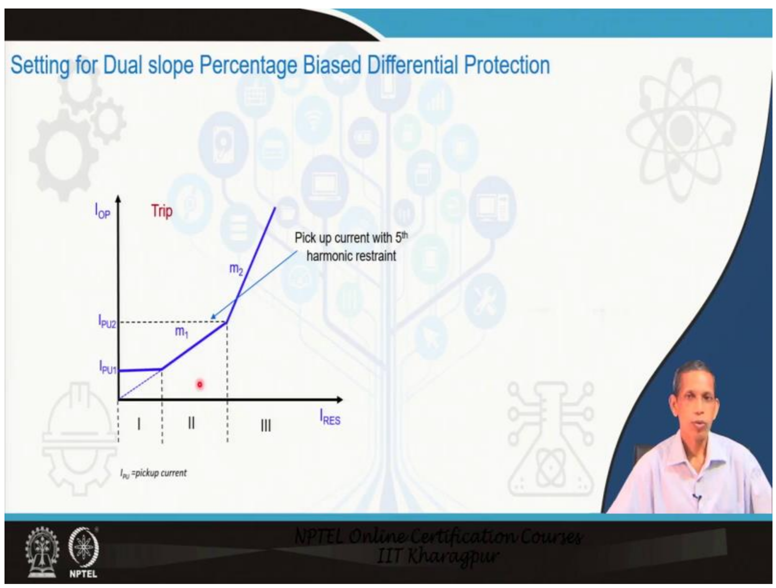

Now, while going the settings and all these things how to, some of the literature suggest that if this is the pickup current then we go for the first slope this line, this line passes through the origin and then it goes to up to this point, this point is nothing but the second pickup level and the second pickup level is decided by this 5th harmonic restraint being provided in the for the percentage by this relay that is for the over excitation phenomena when voltage becomes higher. So, this we will adjust in the subsequent lectures to clarify that perspective and all this things that what is the 5th harmonic restraint and how that is being set in a numerical relay and then begins the high slope region about the m_2 and so and this is what the percentage biased characteristic is being set for a relay in a numerical relaying platform.

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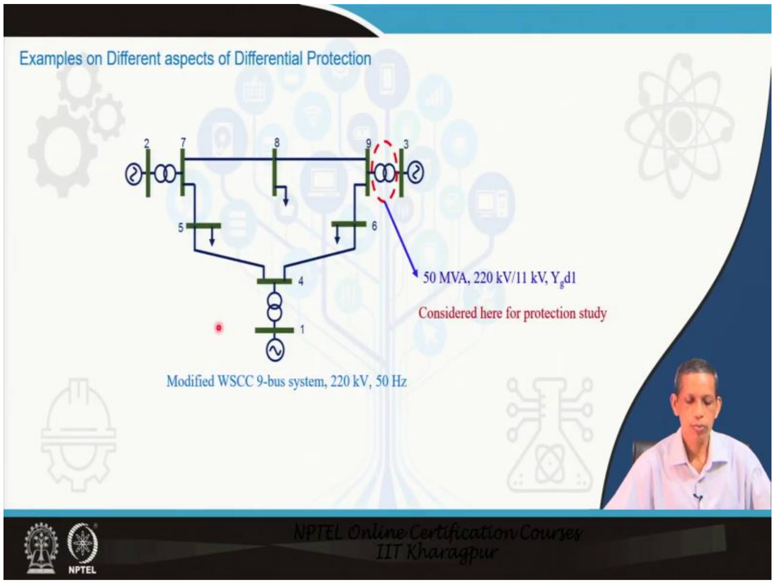

Now, let us go to examples. This is the 9-bus systems and we have considered this for a 50 Hz system, 220 kV level of voltage, we have considered a transformer in this source side, 11: 220 kV, 50 MVA capacity and we have now star grounded delta wire connections, so the vector group is YNd1 connection and all these things. So, this transformer connection can be different that also we will elaborate in the subsequent slides also.

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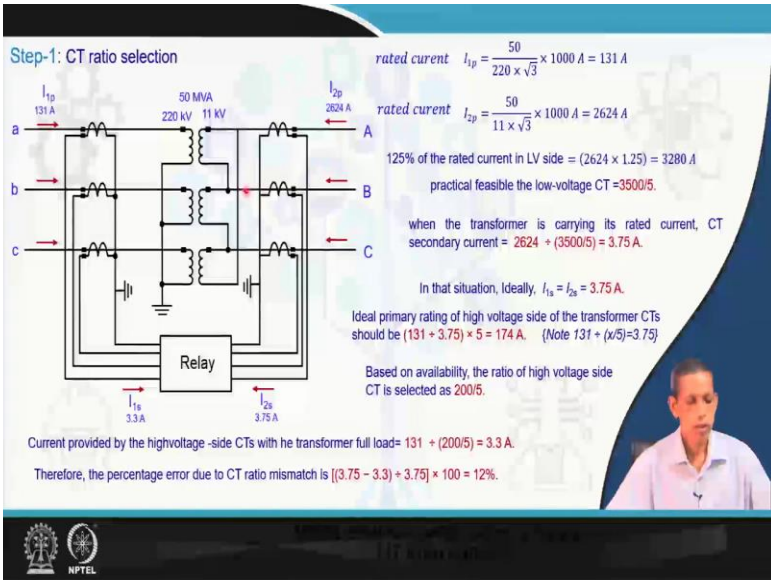

Now, let us for this transformer which we have mentioned in the earlier slide, so this is the transformer connection high voltage state star, 11 kV side, delta low voltage side. Now, in the last lecture, we talk about how to fix the CT that is the first step of the protection because the differential current still we are calculating and which will be analyzed by the relay is based on the current provided by the CT's.

Note that we have already mentioned that numerical relay use the corresponding CT both these sides CT's to be connected in star. So, both these set of CT's are currently in star so with that what will be the corresponding CT ratio selection such as we will see first that perspective, we will fix the CT ratio and then proceed for the further protection in the percentage by relay perspective. So, for this transformer rated current on the low voltage side and the high voltage side are

$$I_{1p} = \frac{50}{220 \times \sqrt{3}} \times 1000\ A = 131\ A$$

$$I_{2p} = \frac{50}{11 \times \sqrt{3}} \times 1000\ A = 2624\ A$$

Now, as already mentioned some utilities follow 125 % of the corresponding current rating for the CT selection. So, this leads to 125 % of this low voltage is= $(2624 \times 1.25) = 3280\ A$. So CT selection is based on the availability 3500: 5.

Now, when this transformer is carrying its rated current, full load current, the CT secondary current becomes = 2624 ÷ (3500/5) = 3.75 A, when this amount of current is flowing in the CT In that situation ideally this side current, the high voltage side current also should be 3.75 A, so our CT selection should be such that the current from this side also should be same amount of current so that the differential current becomes zero and these were the normal situation and then we say that yes our selection of CT's ideal justified.

With that thing considering this same amount of current from this side if we calculate that is why this 131 A, the full load current which will be flowing in the primary divided by 3.75 A which is expected in this side of the secondary of the CT and this is a 5 A CT so then we got 174 A, we got the corresponding one seventy four ampere that correspond to CT ratio. Ideal primary rating of high voltage side of the transformer CTs should be (131 ÷ 3.75) × 5 = 174 A. {Note 131 ÷ (x/5) = 3.75}. So we are going to nearby CT that becomes equals to 200: 5.

So, our final CT selection from the low voltage side is 3500: 5 and the primary side becomes 200:5, so there is some mismatch we expect now because we could not find 174:5 ampere CT and that if we calculate that becomes equals to 131 ÷ (200/5) = 3.3 A but this side current is 3.75 A. So, there is a difference of current even though it is not a fault in normal situation, normal loading condition and that difference is (3.75 – 3.3) A, so that is current divided by 3.75 leads to 12 % error kind of thing in this arrangement. And why this error? Only due to CT ratio mismatch.

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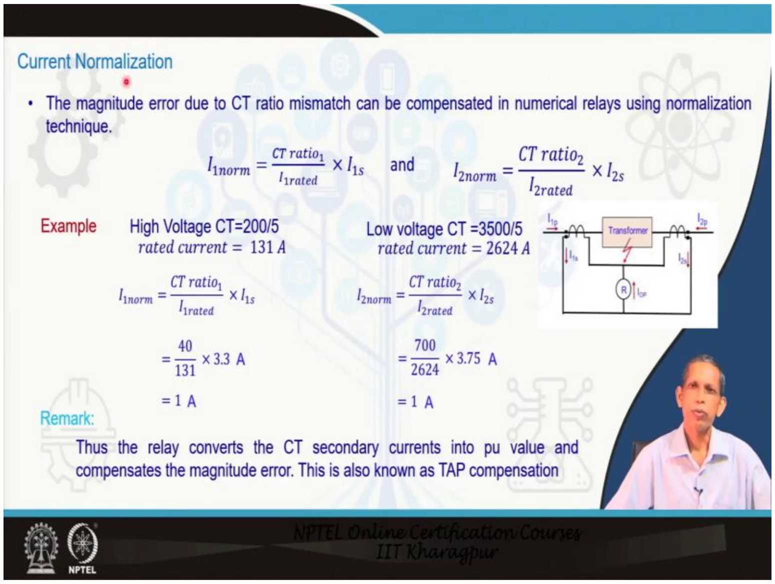

Now, in numerical relay we have enormous scope to calculate, to compensate and to in real time calculation and so and so. So, before going to details how the things are being processed by the percentage by differential relay principle in numerical relay, we will have that terminology called current normalizations. So, why we are doing this? Unless you handle the current properly then the differential current will be very large and then the relay may malfunction. So, to end the accuracy in terms of dependability and security, the reliability perspective will be poor unless we handle the currents properly.

So, what is being done in normalization of the current, is the primary side normalization that becomes equal to

$$I_{1norm} = \frac{CT\ ratio_1}{I_{1rated}} \times I_{1s}$$

So, this secondary current into CT ratio should give you this primary side current of the system divided by the rated current, so that is the normalized current on the high voltage side or the primary side. Similarly, in the second side also, the secondary side also

$$I_{2norm} = \frac{CT\ ratio_2}{I_{2rated}} \times I_{2s}$$

Now, let us see the example which we have considered for the 9-bus system where we have the transformer, 50 MVA transformer for that what happens to there. Note that the corresponding convention which we are using already mentioned is like this for this kind of CT polarity connections.

High voltage CT, we have considered fixed 200: 5 and the rated current we have already found out is 131 A. So, this normalized current becomes

$$I_{1norm} == \frac{40}{131} \times 3.3 = 1$$

Now, low voltage side, CT we have selected is 3500: 5 and the rated current is 2624 A, we have already calculated for the transformer, star grounded delta Yd1 connection. The normalized current in the secondary is

$$I_{2norm} = \frac{700}{2624} \times 3.75 = 1$$

Now, what we see from this is that if you normalize the current, even though you have not got the proper CT ratio as we have already discussed in the earlier slide, if we normalize the current, for the situations we are getting 1 pu this side, 1 pu this side, so, if we use this for normal situation this will lead to zero differential current, so that is a better thing then the 12 % error which you calculated in the earlier slide for the corresponding spill current. So, that is the advantage, to expect the advantage by normalizing the current, the way we get here.

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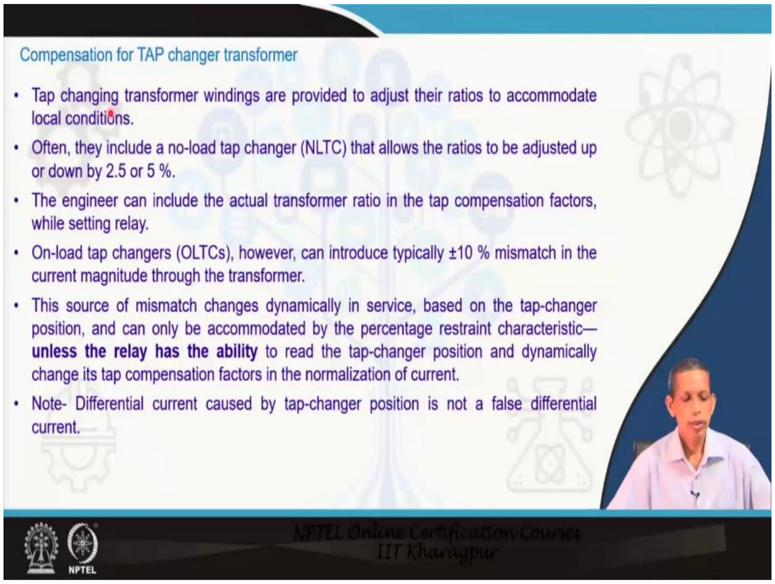

Now, we have tap changing transformer and so and that creates problem in this perspective also, that may also lead to the unwanted false current in the differential branch. Now, tap changing transformer is a common thing in high voltage system applications, two options in tap changing transformer: one is no load tap changer that goes as 5 % changing to change the corresponding voltage generally providing the high voltage side.

Now, the point is that this is at no load, so already the corresponding tap changing is done and that is being accommodated in the setting $N_1 : N_2$ and accordingly the corresponding rated current and so calculated and taken care in this setting, if it is not taken care then the differential current will be there for normal situation also, and the pickup current has to be more or the corresponding m_1 slope has to be more that has to be adjust properly otherwise there will be false trip in the system.

On-load tap changers, so this is more challenging, the on-load tap changers means during different situations in operation of the system the tap changing transformer, the tap position changes and thereby the corresponding differential current is expected to be high even though it is no fault or so. Now, numerical relay today has the ability to adapt the situations, calculate the corresponding tap changing situation and again adjust the corresponding normalize calculation and so including the CT ratio and it can lead to minimization of the corresponding spill current in the system. Now, if it is not that so this tap changing transformer can be ±10% so then if that kind of adjustment is not there in the numerical relay then the corresponding associated mismatch which will happen with this one will be of significant in nature and that must be included in the corresponding percentage wise relay characteristic setting, this is an important factor for this perspective and so because ten percent is not a small value, it is of significant value, so therefore this corresponding m_1 and m_2 are to be adjusted accordingly.

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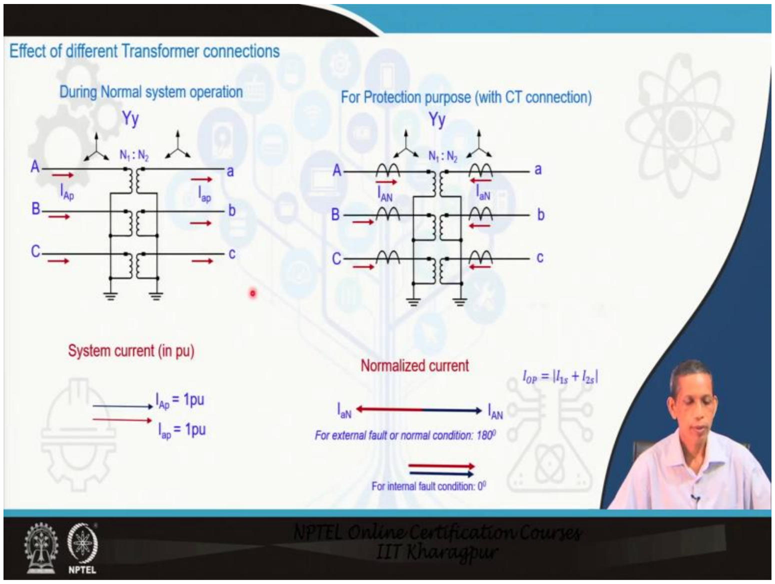

Now, come to different transformer connections how do affect the relaying perspective in the percentage biased relaying applications. Let us take the simple one, star star or similarly delta delta also, so we know they do not have any phase difference, we consider Yy zero degree phase difference, so this is the system side current, high voltage side is capital Y, capital A corresponds to high voltage side, small *a* corresponds to low voltage side, both are having star grounded, so this is the primary current and this is the loading condition current flowing this one.

So, the system current for this one, for system current, no issue of protection we are discussing, the per unit current I_{Ap} and this I_{ap} to voltage side current they align with zero degree reference. And if we talk about the normalized current so that becomes the same magnitude, and let us come to such a protection of a transformer. So, now we connect the CT's as we have already defined, already mentioned that with proper polarity connections and all these things. So, with CT connections we must consider that the current flow is in zone towards the zone. So, now the corresponding for this case normal situations the corresponding this current will be reversed.

So, when you go to the normalized current means the CT secondary current and divided, multiply that factors which we have already considered in the earlier example. For this I_{OP} current to be I_{1s} plus I_{2s} principle. Then for this situation, normal situation the I_{aN} and I_{AN} will be in phasor position with this kind of CT connections which we have discussed, so it will be 180^0 and for an internal fault when the fault becomes internal this is for normal flow condition and when the corresponding current becomes internal that will be the right hand side will be out of phase as compared to this they will be aligned with zero degree. Now if we take the operating current to be I_{1s} plus I_{2s}, so these two will be added, so differential current will be significant for internal fault, so that is what we see in terms of this, that is what is desirable, and for internal fault this becomes 0^0, for external fault this becomes 180^0.

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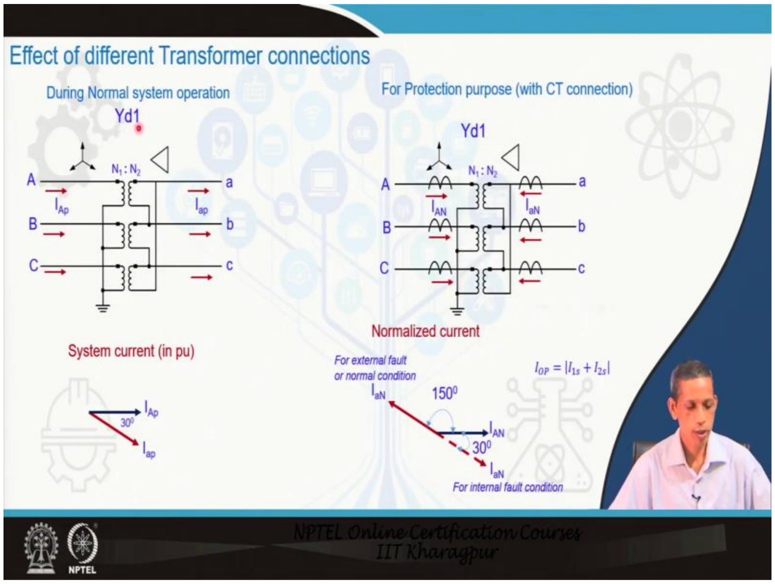

Now, come to Yd1 connection for this transformer. So, we know high voltage leads the low voltage by 30^0 so per unit current, so the high voltage current leads the low voltage current by 30^0. When you come to CT connections as we have already defined, so the normalized current after the scaling down as we have done in the earlier example, so this current will be reversed, so therefore what happens that if we consider these currents to be reversed, so this I_{AN} this side current will be reversed after the CT case condition, so this is about the CT secondary we are looking at. With respect to the high voltage side current the corresponding, the low voltage current will be making an angle of 150^0 and this is in the CT secondary side for normal or external fault condition. But for internal fault conditions, the current direction will be reversed to that and then that will be it will making thirty degree to the high voltage side current. So, this is what we see here. But note that our objective I_{OP} to be I_{1s} plus I_{2s}, so, it means that this low voltage side current should be align in the direction of the high voltage side, means that this 30^0 has to be compensated for that perspective, so that is what the requirement that the phase has to be compensated in case of a Yd1 connection or so.

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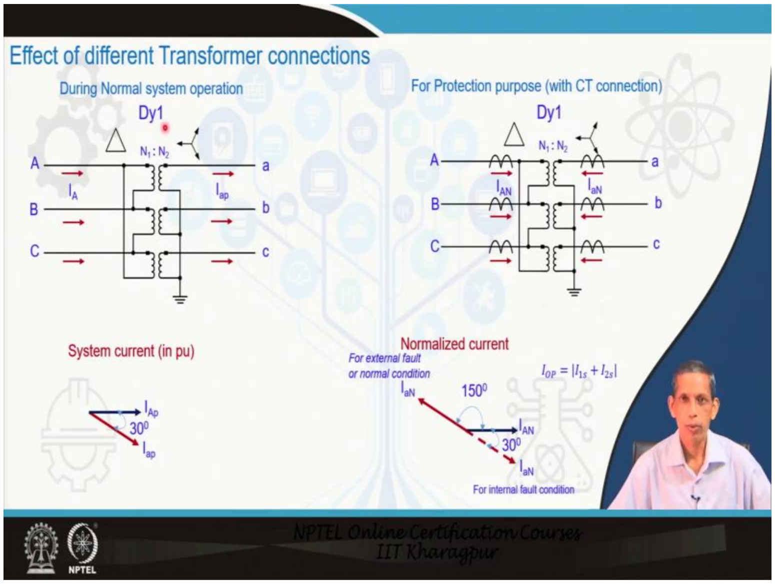

Now, go to the Dy1 high voltage side is delta and then y, so high voltage side leads to the corresponding low voltage side by 30^0, this is what the connection says so system side current similar to what we have discussed earlier. Now, come to with CT connected and in the secondary side current, normalized current. So, 30^0 lags this here, so because of the CT connections this will be reversed, so therefore to the primary voltage, high voltage, the high voltage side, the low voltage side we can say that making an angle of 150^0 and this is external for all any loading condition, normal loading condition. But for internal fault again it will be making30^0, so like earlier case this phase angle has to be compensated so that the small I_{aN} will be aligned to this the high voltage current phasors.

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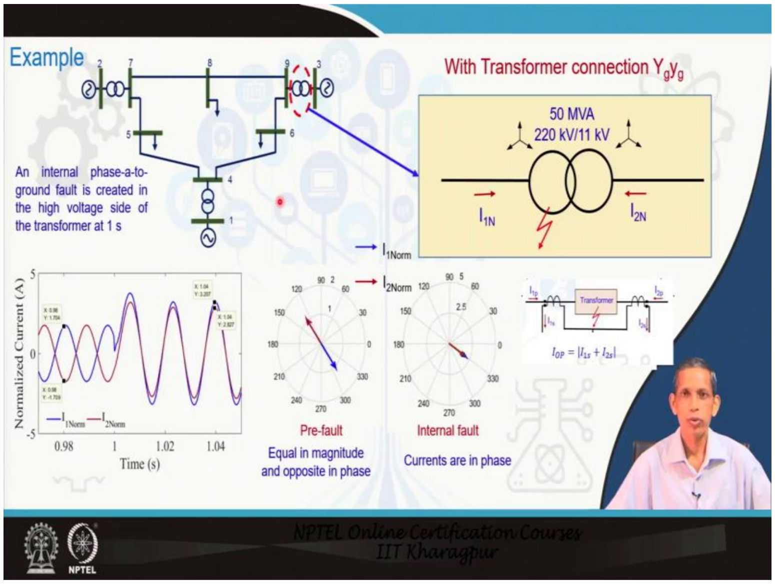

So, coming to applications for that 9 bus system and transformer, we see now, suppose an internal fault phase A to ground fault is being created at one second and then the corresponding phasors the normalized current secondary current in the CT's which you have selected for the high voltage and low voltage side, so this is the star grounded, star grounded, star grounded transformers with these convention of CT connections and so. For an internal fault case, this is an internal fault case, so we have both normalized current and primary and secondary side, blue is for the high voltage side and red is considered is for the low voltage side, we consider through our discussions one, that is primary or so that one side is the high voltage side, two, as the low voltage side that the convention we will be using throughout. So, we see during normal conditions they are out of phase 180^0 and during internal fault situations phase angle is 0^0. So, these additive things makes the operating current to be significant and the subtracting things makes the operating current to be negligible and that is what desirable also that the differential current during normal situation should be zero ideally, but during internal fault situation of this region this should be the differential current should be significant and this phasor gives us that one. So, in this case we say that we do not require any phase compensation or so what we mentioned earlier for the star grounded, star grounded situations with zero degree phase difference between primary and the secondary.

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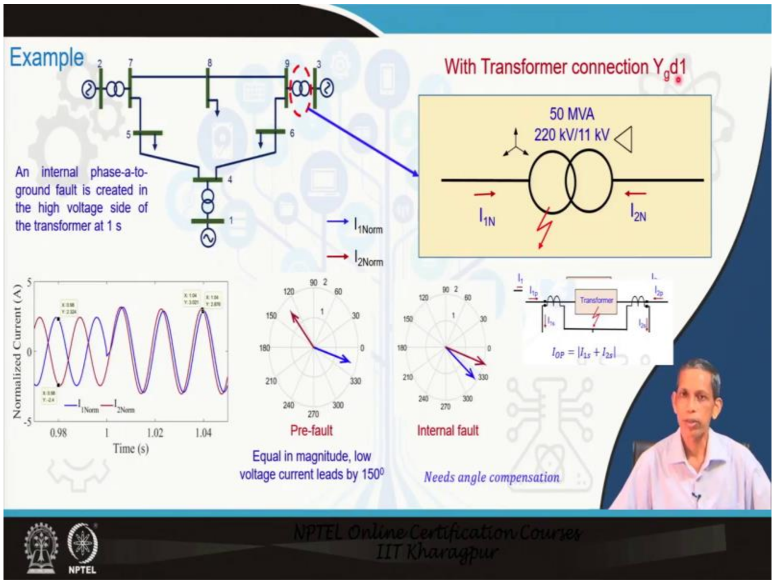

Now, come to the Ygd1 connections of the transformer, same situation for internal fault phase A to ground in this system and then you see primary side here for this case because of the Yd1 connections, the angle becomes 150^0 and for internal fault case the angle becomes 30^0 which we have already discussed earlier. So, therefore what we essentially need, we have operating current significant align the corresponding low voltage current can be aligned to the high voltage current perspective, we need to consider angle compensation here.

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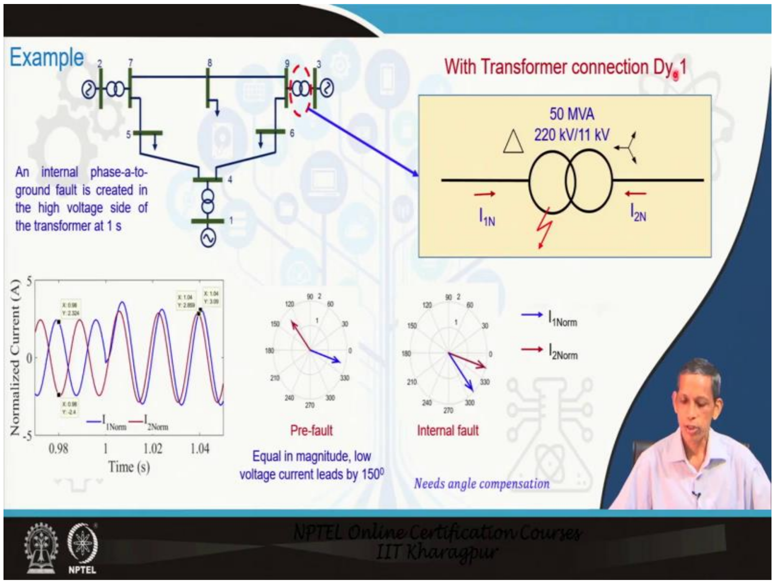

Now, for the Dy1 connections similarly, we found the corresponding current and voltage to be this, again same 150^0 and 30^0, so here also we need angle compensation to be there. Typically this kind of angle compensation is done in earlier version of analog relay and by connecting the CT's in star and delta for a delta star transformer, but now in numerical relay that is not being done, so all the phase compensation is being done in the numerical calculation perspective. How that is being done for the different vector group transformers and all these things, we will clarify more on next lecture on that perspective.

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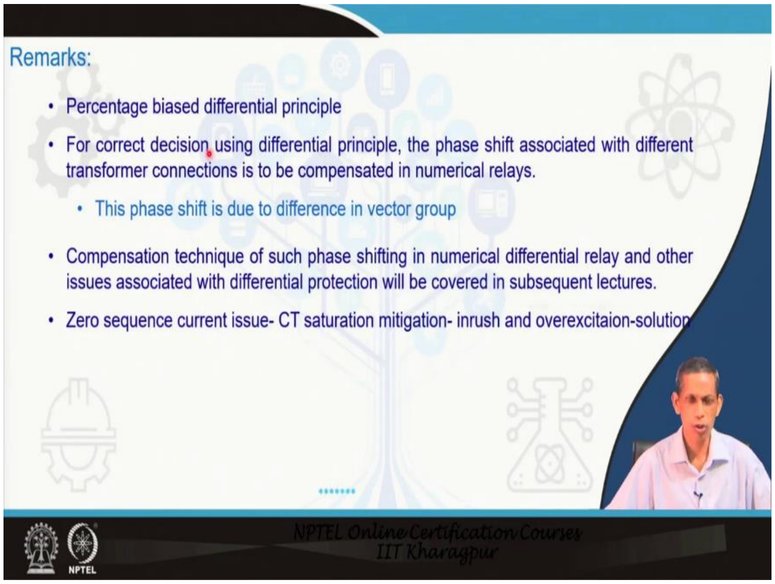

So, in overall, in this lecture we say that percentage biased differential principle is a good solution for transformer protections to adjust CT mismatch, tap changing transformer issue, CT saturation and other challenges in terms of that. For correct decision using differential principle, the phase shifting perspective has to be adjust for different vector group transformer and that must be adjust properly that we will learn from the examples and phasor diagram. The compensation techniques for that will be addressed in our next lecture that I already mentioned. In addition to that zero-sequence current flows in the star grounded side, not in delta side that also is to be adjust which we will see in the next lecture in more details. Thank you.