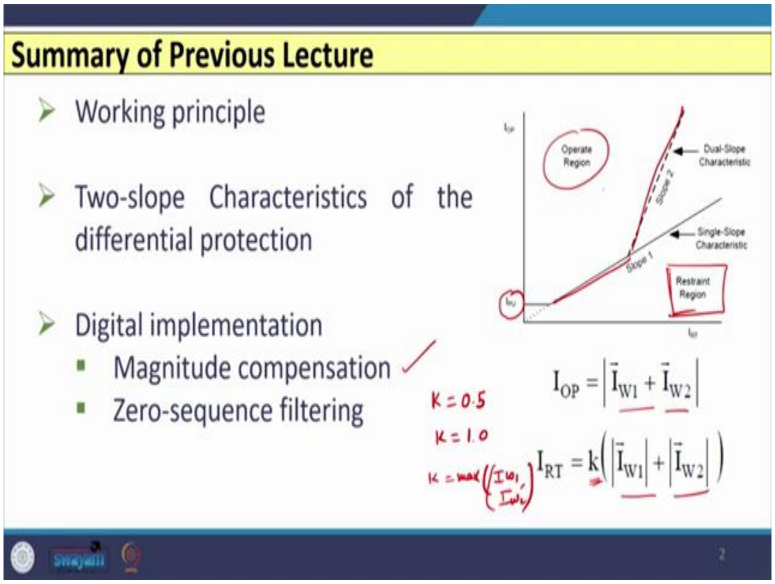
Digital Protection Of Power System

Professor Bhaveshkumar Bhalja
Department of Electrical Engineering
Indian Institute of Technology, Roorkee

Lecture 13
Digital Protection of Transformer-III

Hello friends. So, in the previous lecture, we have discussed regarding the working principle of biased or percentage differential protection scheme. And in that we have discussed the advantages and disadvantages of this scheme, which is widely used by the utilities.

(Refer Slide Time: 00:42)



Thereafter, we have seen the working principle of digital differential relay and in that we have discussed that, if we use Two-slope characteristic, then the operating current that is obtained by the vectorial addition of two CT- Secondary Currents fed to the differential relay and the restraining current that is obtained by scalar addition of two CT- Secondary Currents.

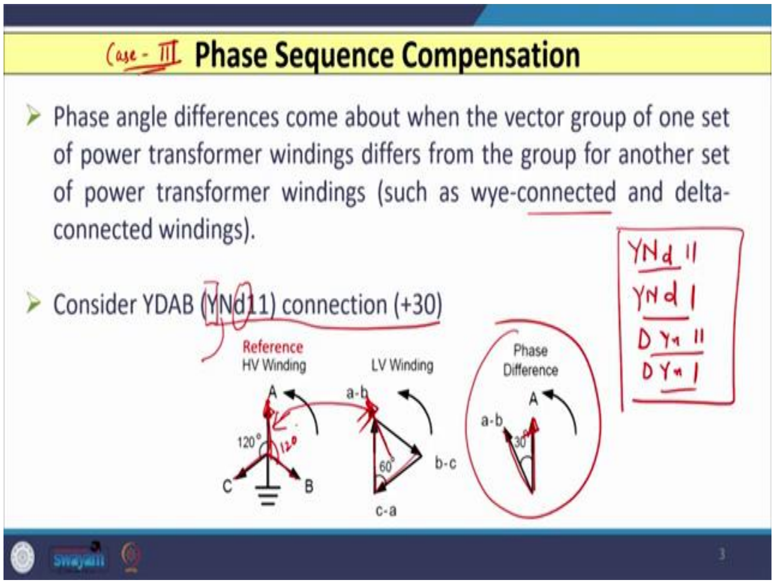
That is multiplied with some compensation factor k, which is normally considered as either k = 0.5 or we can consider k = 1.0 or we can consider k that is max of I_{W1} and I_{W2}. So, any value depending upon application we can select and this we have discussed, we have also discussed that the importance of this I_{PU} setting which is a initial threshold which has two cross and then we have discussed the Slope-1 and importance of Slope-2.

So, this we have discussed and we have seen that if any operating point comes or falls in this region above this characteristic, then that is known as operating region and relay has to operate. And if any point falls in this region below this characteristic, then relay should not operate and it has to block. So, after that we have discussed that if we wish to use digital differential relay in the power transformer, then we need to use certain compensation.

So, magnitude compensation and zero sequence compensation in the digital relay for the application of power transformer that can be achieved mathematically by using equations and we have discussed that if we use these equations in digital relay, then compared to the earlier bias or percentage differential relay, there is no need of ICTs or interconnecting transformers.

So, this is one of the important point. And second point which we have discussed is that in digital relays, the CTs which are connected either on HV side and LV side, they are connected in star only as we have discussed that earlier that is bias differential or percentage differential relay, if your HV winding is star connected, then CTs on this side are connected in delta and vice versa with this way we can avoid the phase shift and zero sequence compensation we can achieve however, in digital relay, all the CTs are connected in star fashion. And we have seen that the reason is we want to reduce the burden of the CT and so that if burden can be reduced then the chances of CT saturation that also reduced.

(Refer Slide Time: 03:53)



So, now with this background, let us consider the third case that is the how we can achieve the phase shift compensation in case of the digital or numerical relay. So, whenever we consider a particular vector group or winding connection in the power transformer, let us say it involves delta-connected winding with star connected winding, then we can have let us say the connections are star grounded with delta-11.

We may have the connections star grounded with delta-1 or we may have the reverse that is delta star neutral and maybe 11, and maybe delta star neutral 1, because these are the commonly used winding connections or vector group in case of power transformers. So, when we have such type of vector group or winding connections, then the inherent phase shift already exist on the LV side or secondary side compared to the HV side or primary side of the winding.

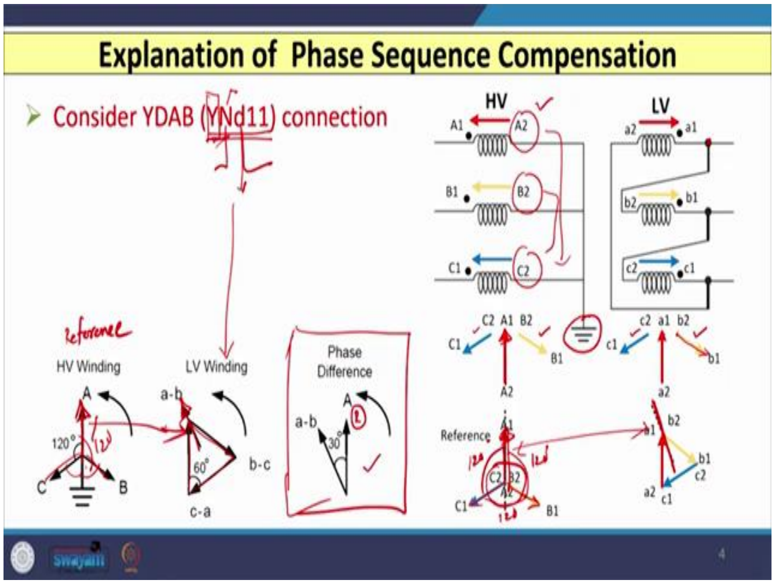
So, in this case when such phase shift exists, we cannot que this signal to the relay and we have to compensate it because earlier we have discussed that whenever two currents we will give to the relay, this current should be equal in magnitude as well as in phase. So, to consider these how we can remove the phase shift or phase sequence compensation in digital relay, let us consider one transformer winding connection or vector group let us say it is star grounded delta-11 connection. So, here you can see that, when we consider the star connection with neutral of that star is grounded the phasor we can have they are 120° displaced with each other.

So, we have the phasor like this and normally in all the cases we consider the HV winding as a reference phasor. So, on the other hand, if I consider the delta winding, then we can have the delta winding with a-b, b-c and c-a like this. So, we have the phasor like this and if you compare this phasor and this phasor that means, these two then you can have phasor diagram like this.

Where this I have considered as a reference and you can see that with respect to that the LV side phasor that is always leading with reference to the HV side phasor and that difference is 30°. So, now, let us consider the third case that is the phase sequence compensation in digital relay. So, when we consider the digital relay, we know that there are different vector groups exist in the digital relay.

So, whenever we have a winding connections particularly like delta star 11 or maybe star delta 1 or delta star 11 or delta star 1, then we have to compensate the phase shift exists between the LV winding and HV winding. So, let us see how we can achieve this. So, to understand this, let us consider one example.

(Refer Slide Time: 07:18)



So, here I have considered the example of the star delta 11 connection. So, here you can see (as shown in above slide) that the star connection is grounded the meaning of N, that means the star is grounded. So, the phasor I have shown here which are 120° apart with each other and your neutral of the star is grounded and then we have the LV winding that is delta. So, we have the LV winding it is connected in delta and if you see the phasor of this, then the phasor looks like this.

So, if you compare this phasor HV winding phasor which is normally considered as reference with the LV winding phasor then you can see (as shown in above slide) that you will have the phasor diagram like this. And if I consider this as the reference that means HV winding phasor as the reference then compared to that LV winding phasor is leading by an angle 30°.

So, let us see how this is achieved or how this is possible? So, if I consider the HV winding at the star winding that is first is the HV winding that is star N. So, we have considered here HV winding in three phase form that is star connected and the neutral of this is grounded you can see here and if I consider the phasor with specific dot.

Then you can see I have shown the phasor from A2 to A1, B2 to B1 and C2 to C1. So, you can see that all these three points A2, B2 and C2 they are connected at same point. So, if I draw the phasor diagram, because you know that these three windings in each phase they are mechanically 120° apart.

So, you can see that this phasor which is A2 to A1 in our phase that is like this, in another Y phase you can see (as shown in above slide) the phasor is from B2 to B1 like this and in C phase the phasor is from C2 to C1. So, if I arrange these three phasors in 120° apart because the coil itself is connected in 120° apart, so, we have and as A2, B2, C2 are connected together.

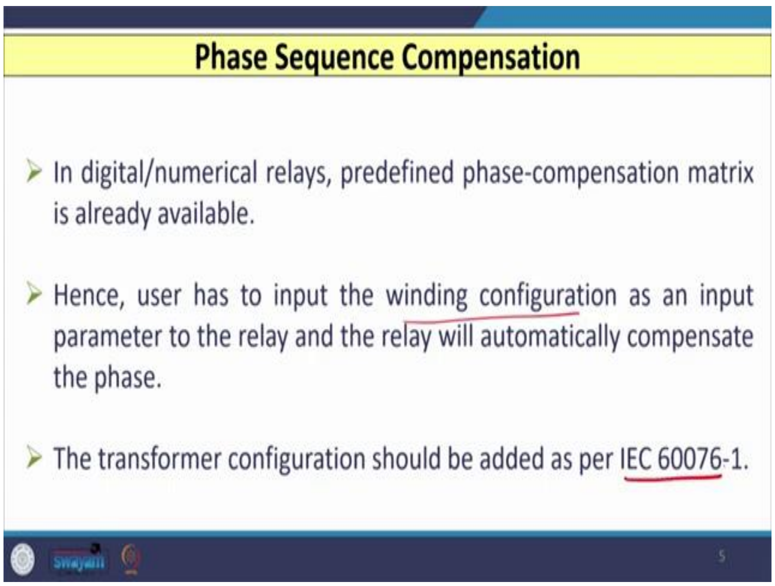
So, from A2 to A1 we have first phasor again B2 to B1 phasor is 120° apart and B2 and A2 are connected together so we have another phasor and similarly we have the third phasor from C2 to C1 So, here are all the three points A2, B2 and C2 they are connected together at same point and they are 120° apart with each other.

Now, similarly, if I consider on the LV side that is the delta here. So, you can see that I have shown the winding phasor from again a2 to a1, b2 to b1 and c2 to c1 in RYB phase respectively. So, here you can see (as shown in above slide) that the three phasors are from a2 to a1. So, this is your first winding phasor, the second winding phasor is from b2 to b1 that is this one and third winding phasor is from c2 to c1.

Now, here you can see that (as shown in above slide) your a1 point is connected with the b2 point. So, your first phasor in our phase that is from a2 to a1 and as a1 is connected with b2. So, b2 to b1 phasor I have to put it here and this point is connected with this. So, that is why I have shown b2 to b1 phasor here. And similarly, c2 to c1 phasor at c2 is connected with b1, so, you can put this phasor like this. So, if you draw the reference then you will have the reference like this and for this star winding you have the reference like this (as shown in above slide). So, if you compare this two phasor then you will have this value.

So, we can conclude that if we consider the star grounded delta 11 connection then with reference to the HV winding, your LV winding phasor is leading by an angle 30°. So, normally in all electrical connections the leading angle is denoted by plus and lagging angle is denoted by minus.

(Refer Slide Time: 11:52)

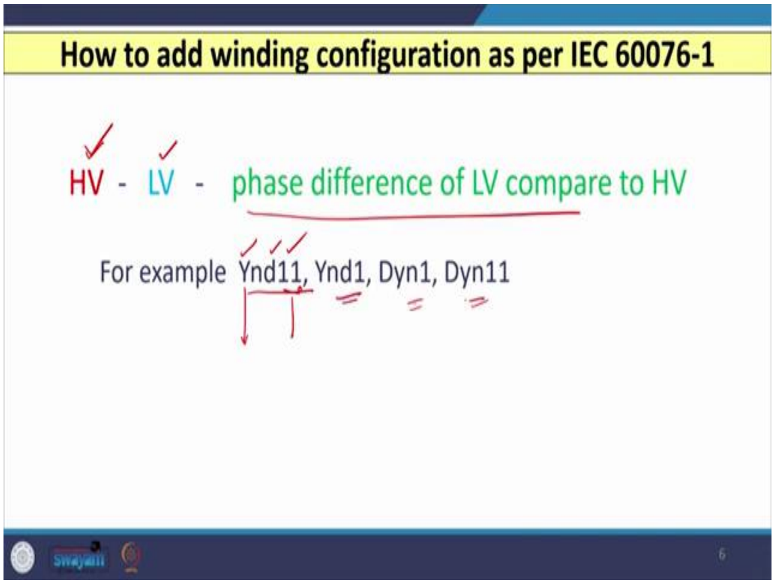


Now, when we consider the any digital relay or numerical relay, in that case the most of the users or utilities or manufacturer, they will provide a Phase sequence metrics depending upon the vector group or winding connection. So, as a user, if I is let us say if I want to use delta star 11 connection.

Then I have to just simply enter in digital relay, the specific winding connection or vector group as an input parameter to the relay and based on that vector group, which is given or input by the user digital relay will automatically compensate the phase shift exist between LV and HV winding. Because you have already input the vector group or winding connection for that particular winding connection a specific compensation metrics is selected and based on that compensation is carried out.

Now, the question comes in what fashion we have to input the winding connection or vector group. So, in for transformer depending upon what configuration we are used, we have to enter the winding configuration or vector group as per IEC 60076-1 standard. So, let us see what does, this standard indicate.

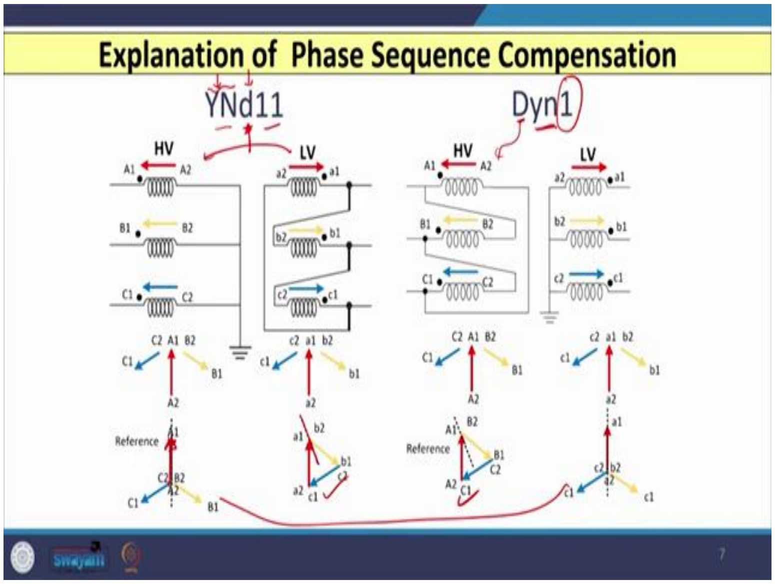
(Refer Slide Time: 13:13)



So, as per this IEC 60076-1 it is mentioned that first you have to always mention the HV winding, then you have to mention the LV winding and after that you have to see that phase difference between the LV compared to the HV and always your HV winding that will be considered as the reference phasor.

So, for example, if I consider star grounded neutral is grounded with delta 11 connection, then this is your HV winding that is star your LV winding is delta and the phase shift between that delta and star that is 11. So, here the meaning of 11 is that your LV winding phasor which is delta that is again leading by an angle of 30° with reference to your HV winding phasor that is star. So, same way you can have the other connections reference.

(Refer Slide Time: 14:14)



Now, with this background, let us check one more thing. What is the similarity between the two windings? So, if I consider star grounded delta 11 connection, so, this is your HV winding that is star grounded, this is your LV winding. So, that is delta is LV and 11 is the phase shift exist between two windings.

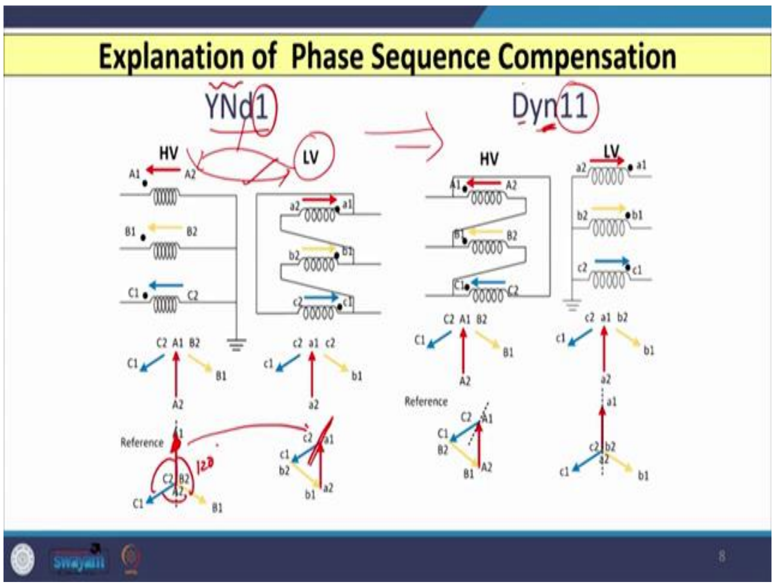
So, here we have already discussed that if I draw the phasor diagram for this star grounded neutral delta 11 connection, then we have the reference phasor that is always with HV winding that is star and we have the delta side or LV side phasor is like this. So, we have 11 o'clock connection so, your LV winding phasor is leading with reference to HV winding phasor by an angle 30°.

However, if I swept the delta winding that means if I took this LV winding on other side means I assumed that now my HV winding which we are taking as a reference let us say that is my delta winding. So, my LV is coming as an HV winding and then my HV winding is becoming LV winding.

So, that connection is probably now you can see here you have the HV winding is delta so, that comes first with capital letter and your LV winding is always in small letters so, that is again after the HV winding. So, that is start with neutral of that winding is grounded. So, here the only difference we want to consider is that this phase shift you can see that when your star is HV winding and delta is LV winding.

The phase shift is 30° and your LV winding phasor is leading with HV winding phasor by 30°. Now, as you swap it now, your LV winding is star connected and your HV winding is delta connected. So, if you draw the reference phasor you will have the same phasor like this (as shown in above slide), but the only difference is now your reference phasor is delta winding that is your HV winding. So, now, you can see that your LV winding phasor is lagging by an angle 30° with reference to HV winding phasor.

(Refer Slide Time: 16:37)



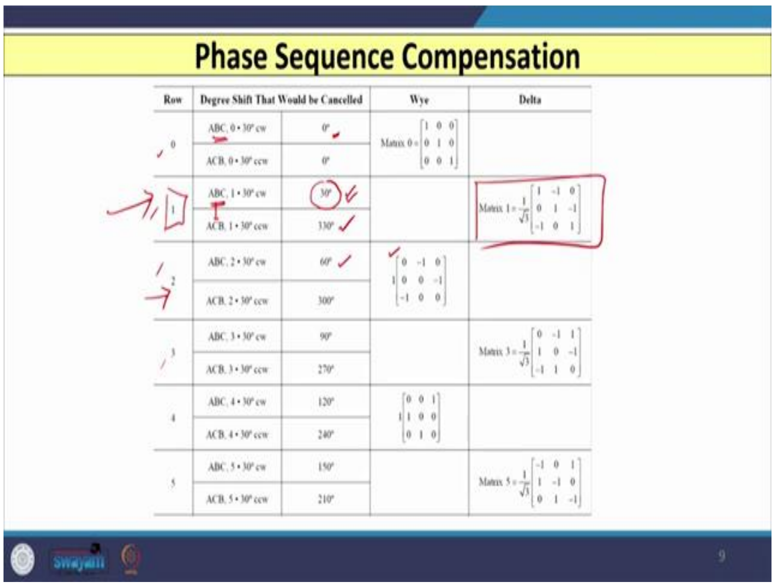
Similarly, if I consider the other connection let us say star neutral grounded with delta-1 connection then you can see that I have shown the diagram here and you can see that the three phasors as your HV winding is your star with neutral grounded. So, you have the three connections they are 120° apart phasors.

And this is your reference phasor and on LV side which is delta connected if you draw then you have the reference phasor like this and if you compare these two as the name suggests it has 1 o'clock connection. So, that means your LV winding phasor is lagging with reference to HV winding phasor by an angle 30°.

Now, if I swap let us say this LV winding is becoming a HV winding and my HV winding is becoming LV winding. So, that I have shown here. So, now, my connection is your HV winding is delta. So, D is capital and my LV winding is star grounded, but the only change that is going to occur is the phase shift between the two phasors.

So, here when we consider Dyn 11 connection, then you can see that your the LV winding phasor which is star connected that is again leading with reference to your HV winding phasor by angle 30°.

(Refer Slide Time: 18:05)



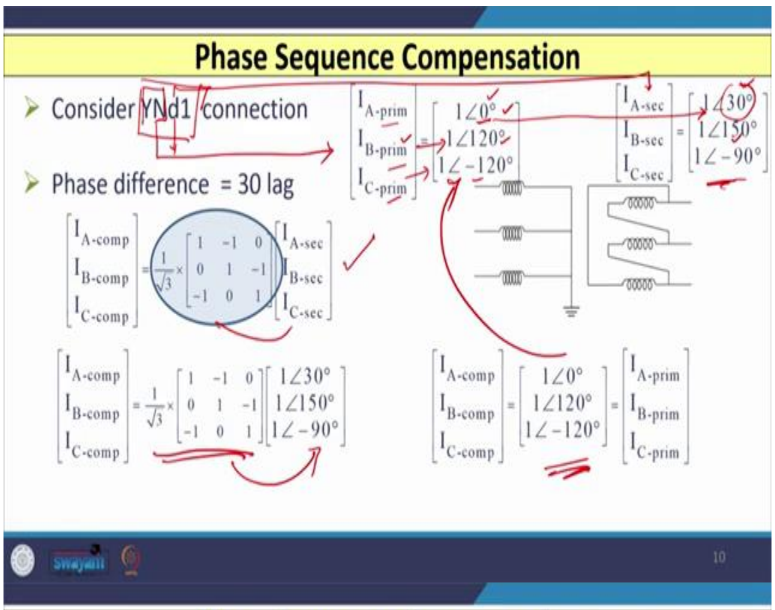
So, how to do or how to tackle this in a digital relay? So, in a digital relay most of the manufacturers will give the phase sequence compensation metrics. So, I have shown one table here (as shown in above slide) in which first column indicates the Row, the second and third column together that indicates the phase sequence and what degree of compensation we required.

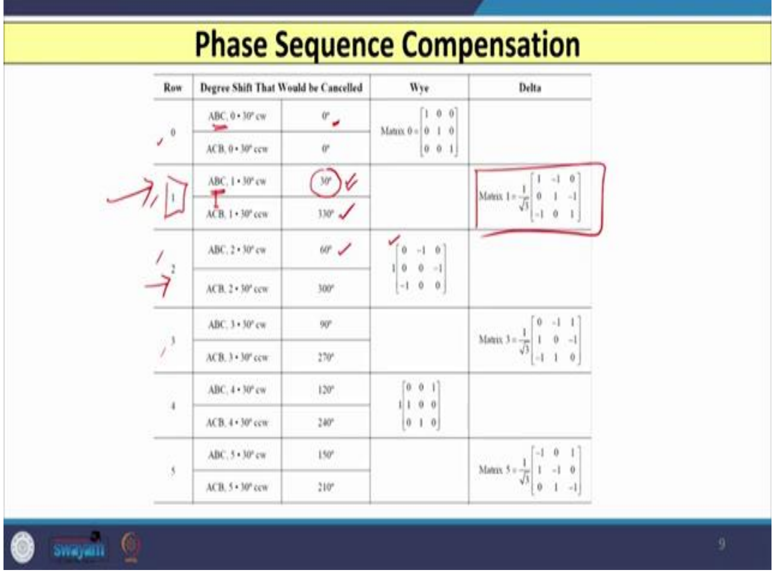
So, for example, if I consider let us say the Row number 1, in which the face sequence is let us say ABC. So, in that case, we need 30° compensation in clockwise direction and if we replace or if we change this phase sequence from ABC to ACB then we need a 330° phase shift in counterclockwise direction.

So, degree of phase shift which we need to cancel that is either 30° in clockwise or 330° in counterclockwise direction and accordingly let us say I want to cancel 30° in clockwise direction, then you have to multiply your delta side currents or whatever signals you have with this metrics. So, that, that 30° phase shift that can be compensated same way if you consider let us say this one, second one, where the Row is 2, so here 2 number is multiplied with 30°, because 30 is your base or reference.

So, now you want to cancel the 60° phase shift and that 60° phase shift that can be compensate by multiplying of course in clockwise direction with Wye with this metrics. So, same way for whatever degree of phase shift you want to cancel with the reference to the specific phase sequence you have to multiply either delta side or star side signals with the specific metrics.

(Refer Slide Time: 20:07)





To understand this let us consider one example. So, let us see one specific connection that is star neutral d1 connection. So YNd1 connection. So here your HV winding is star with the star point is grounded and your LV winding is delta and the phase shift exists is the 30°. So, the meaning is that your LV winding phasor that is delta that is lagging by angle 30° with reference to your HV winding phasor which is in star connection. So, you can see that my HV winding currents I have shown here I_A-primary, I_B-primary and IC-primary phase wise. So, I_A-primary is $1 \angle 0°$, I_B-primary is let us say $1 \angle 120°$ and I_C-primary is $1 \angle$ minus 120° or $1 \angle 240°$.

Now, on the other hand, if I consider the delta side currents, which I have denoted as secondary. So, my I_A-secondary will be, because, as I told you the meaning of YNd1 is my delta side phasor, that is again lagging by an angle 30° with reference to star side. So, compared to this you can see that here the phase shift that is 30°.

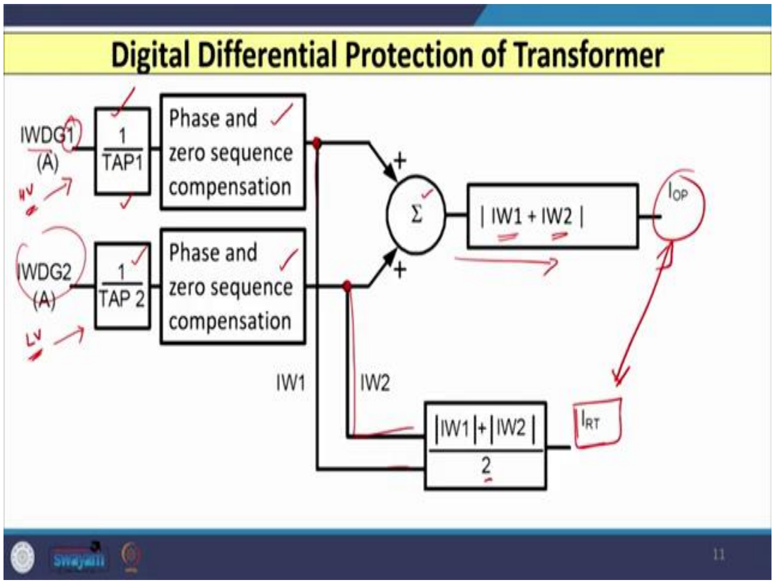
So, this will start at 0° whereas, this will start after 30°, same way for B phase on primary side it will start at 120° where this will start at 120 + 30. So, that is 150° and same is the case with the C phase. Now, as I told you, we want to compensate this 30° phase shift or we want to cancel this 30° phase shift.

So, as I have explained earlier that if I want to cancel or compensate 30° phase shift, I have to multiply my delta side currents with these metrics $\begin{bmatrix} I_{\text{A-comp}} \\ I_{\text{B-comp}} \\ I_{\text{C-comp}} \end{bmatrix} = \frac{1}{\sqrt{3}} \times \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_{\text{A-sec}} \\ I_{\text{B-sec}} \\ I_{\text{C-sec}} \end{bmatrix}$

So, this metrics I have multiplied with the values that is I_A-secondary, I_B-secondary and I_C-secondary and when you solve this, the value available that should be exactly same as your I_A-primary, I_B-primary and I_C-primary that is $\begin{bmatrix} I_{\text{A-comp}} \\ I_{\text{B-comp}} \\ I_{\text{C-comp}} \end{bmatrix} = \begin{bmatrix} 1\angle 0° \\ 1\angle 120° \\ 1\angle -120° \end{bmatrix} = \begin{bmatrix} I_{\text{A-prim}} \\ I_{\text{B-prim}} \\ I_{\text{C-prim}} \end{bmatrix}$

So, your compensated value of three phase currents in A, B and C phase that is same as your original value which you want.

(Refer Slide Time: 23:08)



Now, with this background, we have discussed three cases initially we started with the magnitude compensation and which we have achieved using tap equation, then we have discussed the zero sequence compensation and then last we have discussed the phase sequence compensation.

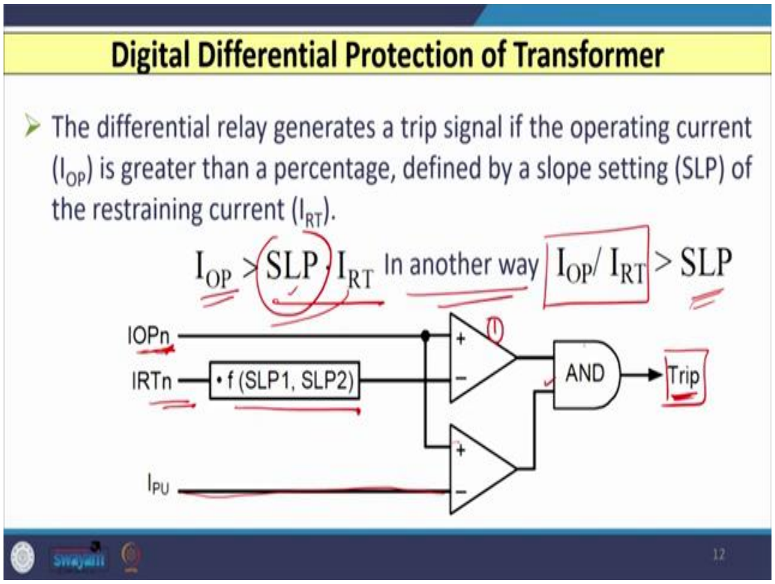
So, let us see if I use all three compensations in a digital or numerical relay, then how my relay will look like and how we can achieve the operating current and the restraining current. So, here let us consider the two windings one is your HV winding and another is your LV winding. So, let us say this is your HV winding and let us say this is your LV winding, you assume that whenever I say HV winding three phase currents are there or three phase quantities are there.

Similarly, for LV winding also three phase currents are there. So, the first block that is your magnitude compensation using TAP equation maybe on one winding site. So, IWDG1 that is your winding, so, current I is current, WDG is winding 1 is the first winding or HV winding. So, that is compensated means magnitude compensation is done by this TAP equation and then we want phase sequence and zero sequence compensation.

So, that also we can achieve mathematically using metrics and similarly, for the other side winding that is IWDG2 we have magnitude compensation and phase and zero sequence compensation and both this value will be given to the summing block and if you finally have the operating current which is nothing but the vectorial addition of two currents that is from one winding and another winding or that is from HV winding and LV winding. So, if you have three currents in HV winding RYB and similarly, three currents in LV winding that is also RYB then you have to do this addition vectorial addition phase wise. Same way, if I want to obtain the restraining current that is I_{RT}.

Then that also you can obtain because you can see I have considered the same two signals here and that is nothing but we are going to do simply the scalar addition with specific compensation factor k here I have considered k = 0.5. So, you will have finally, the restraining current I_{RT}. So, once we have the both operating current I_{OP} and restraining current I_{RT}.

(Refer Slide Time: 25:50)



Then we will have the logic with the help of the slope characteristic. So, let us see how the digital or numerical differential scheme that is going to achieve the protection for power transformer. So, we have the operating current and that operating current should be greater than the restraining current multiplied with some slope values.

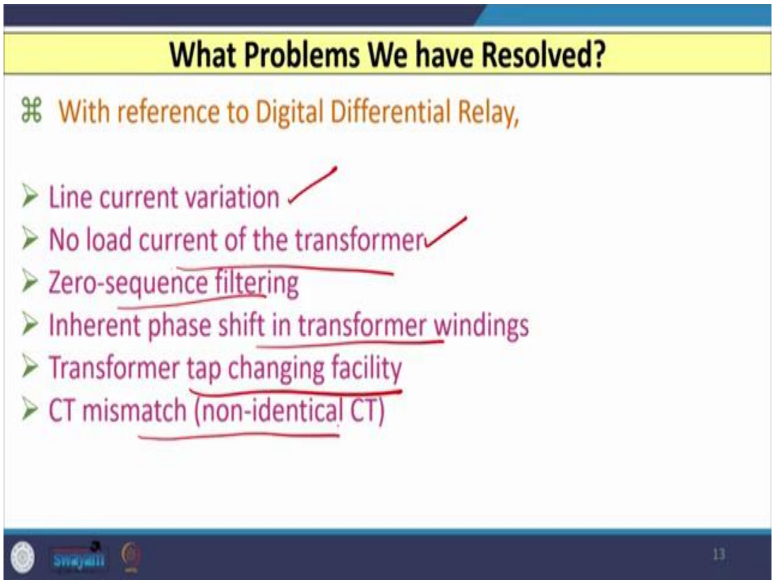
If you have let us say a single slope characteristic SLP that is only for one slope, if you use dual slope characteristic, then you can go for slope 1 and slope 2 both the values. So, in another way, we can also write down that if I take this I_{RT} on this side, then I_{OP}/I_{RT} > SLP

If I put this in block diagram, then my operating current I_{OP} that is given to operational amplifier, let us say I_{OPn} 1 and this n indicates the discrete values. So, this we are going to obtain from the phasor estimation because we have already discussed the Discrete Fourier Transform and some other methods to estimate the phasor.

So, you will have one value of operating current that is phasor value, you will have the restraining current also in phasor form and that is multiplied with the slope depending upon whether you use single slope characteristic or you have used the dual slope characteristic and that is given to the AND GATE.

And similarly, we have the I per unit (I_{PU}) that is the basic threshold and that is again also given compared with the operating current I_{OP} and that output is given to the another end of the AND GATE. And finally, you will have the trip signal. So, if my operating values are greater than restraining value, and if my operating values are greater than I_{PU} initial threshold, then the relay should initiate a Trip command and your circuit breaker that will be tripped. Now, with this background, let us see what we have discussed.

(Refer Slide Time: 28:08)



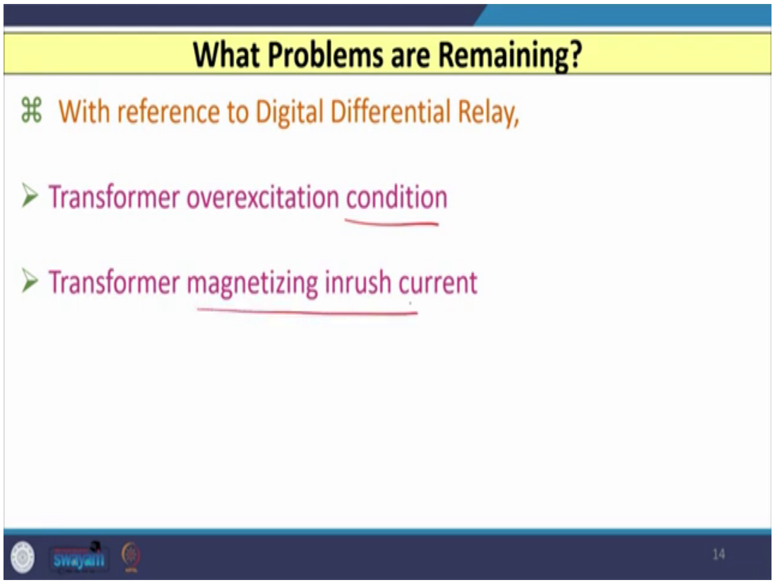
So, we have resolved with reference to our digital or numerical differential relay, we have considered the Line current variation. So, if you have HV side or LV side, we have the voltage ratios are different. So, current ratios are also different. So, CT ratings are also different, then we have discussed the NO load current of the transformer.

So, when the transformer is working in steady state condition then the, No load or current is very small then we have obtained the Zero- sequence filtering using mathematical equation, Inherent phase shift also using mathematical equation some metrics and we do have the Transformer tap changing facilities.

So, if transformer or CT values or settings of the transformer is carried out based on the nominal tap, if tap is changed, then there is a change in the spill current and because of that your conventional bias or percentage differential relay may mal operate. However, your digital relay should not mal operate in this case.

And we have also discussed that CT mismatch that is because of the non identical CT saturation characteristic that can be also overcome. Now, what problems are remaining or which we have not discussed with reference to digital or numerical relay.

(Refer Slide Time: 29:32)



That is the transformer overexcitation condition and second, that is the transformer magnetizing inrush current. So, this we will discuss in the next class. So, in this class, we have discussed the one important compensation case that is the third case that is how we can obtained the phase sequence compensation or inherent phase shift exist depending upon the what vector group or winding connection we have used.

So, how we can carried out the cancellation or removal of that phase shift and we have seen that we can use a specific metrics for specific vector group or winding connection and that can be compensated. After that we have discussed that how we can obtain the operating current and restraining current and with that operating and restraining current if we connect through operational amplifier AND GATE then how we can obtain the final trip command.

And then finally, we have discussed that if we use digital or numerical relay, then the all the issues related to CT mismatch or CT ratio mismatch or maybe because of tap changing mechanism or maybe because of the no load current all those are tackled by the digital or numerical relay.

However, two issues which are very important because of which most of the mal operations are observed by the utility in actual field that is because of the over excitation condition and because of the magnetizing inrush current that we will discuss in the next class. Thank you.