Digital Protection of Power System
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Lecture 15
Digital Protection of Transformer-V

Hello friends. So, in the previous lecture, we have discussed regarding the digital implementation of the differential relay that is applicable for the protection of power transformer.

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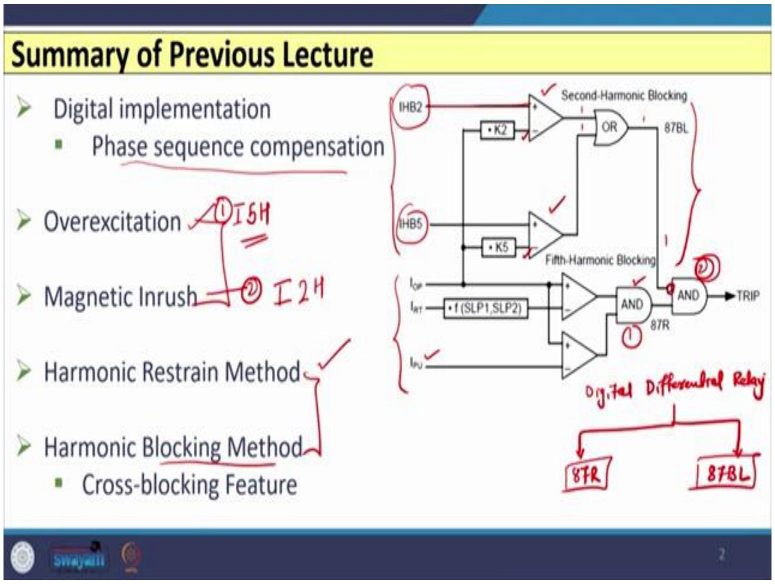

And in that we have discussed the third case that is if we want to compensate the inherent phase shift in the transformers specifically when delta winding and star winding both are involved then we have to go for phase sequence compensation and for each vector group or winding connection user has to enter the vector group or winding connection and based on that a specific matrix is available.

And that is provided by the relay manufacturer and that is multiplied by a respective either the primary or secondary current to compensate the phase shift depending upon what degree of compensation we need. So, that we have discussed in details after that we have discussed two important problems. Because of which the digital differential relay performance may be affected and these two important issues are the first one is the over excitation.

So, when there is a increase in voltage and reduction in frequency, then the over excitation conditions occurs and because of the flow of spill current the differential relay may mal operate. So, in that case, we have summarize that if we go for the harmonic analysis of the waveform of over excitation condition.

Then we found that we can go for the fifth harmonic current, and if we found that the content of fifth harmonic exceeds a certain threshold value, then that condition can be detected otherwise, the over excitation condition is not there, after that we have discussed the second important phenomena that is known as the magnetizing inrush.

And we have seen that whenever we energize the unloaded or lightly loaded power transformer then such type of phenomena occurs depends on many parameters like for example, what is the residual flux remain there in the core of the transformer or what is the source impedance. So, what is the angle at which we are going to energize the transformer.

So, we have also discussed that the residual flux play an important role when we are talking about magnetizing inrush current and we found that after harmonic analysis of inrush waveform, we can go for the detection of inrush current if we go for second harmonic component and if second harmonic component exceeds certain threshold value, then we can block the operation of relay indicating that this is an inrush phenomena and it is not an internal fault otherwise, the tripping can be initiated. So, to obtain that, we have seen two important methods, one is the harmonic restraint method and second is the harmonic blocking method. And in harmonic blocking method also we have discussed the maybe 2 out of 3 blocking or 1 out of 3 blocking or averaging method.

So, in that we have finally, we obtain that if we go for a 1 out of 3 blocking that means, sometimes in certain conditions when like say sympathetic inrush condition is there, then in that case there is a fair chance is that in one of the phases the harmonic content may not exceed the predetermined threshold value.

So, in that case also we need to block the operation of relay and for that we have seen that most of the utility and manufacturers also they suggest 1 of 3 blocking method. So, with considering all these things, we can say that the overall block diagram of the digital differential relay looks like this.

So, in that case, we have discussed that when we have the digital differential relay, then the operation of that relay that can be divided in 2 parts 1 is because of 87 R and another is because of the 87 BL that is blocking logic. So, the 87 R the first part that consists of the lower one where you have the operating current that is given to operational amplifier and restraining current that is also given to operational amplifier.

But through the slope if you have single slope characteristic you can have 1 slope if you have dual slope characteristic you have to input 2 slopes, then we do have the initial threshold setting that is I_{PU}. And we will discuss later on when we solve the example that the what is the significance of I_{PU} and with this that output of this 2-amplifiers are given to the AND gate and the output of AND gate is again given to one of the input of another AND gate that is second AND gate.

And we can see that a tripping is initiated. But in earlier case only lower circuit is available. However, we have included the upper circuit also that is the logic related to 87BL. So, that means, if any inrush condition is detected or any over excitation condition is detected, then the output of this OR gate that is available as 1.

So, final as you know here 0, I have put so, it becomes 0, and hence no tripping command is initiated. So, our objective is that whenever any inrush condition is there may be in any of the phases of the transformer winding or whenever over excitation condition is there, then in that case tripping operation should not be there and that can be achieved using this 87 BL logic.

So, in that case, we have again we use two operational amplifiers and in that case one of the input is given let us say for second harmonic current and here in lower side one of the input is given to fifth harmonic current. And the second input to each operational amplifier is this setting. Let us say K2 multiplied by operating current and K5 multiplied by again operating current that is your predetermined threshold value.

So, in any case if inrush is detected or over excitation condition is detected, this will become 1. So, your output of OR logic becomes 1, so, that the final output of this second AND gate that is 0. So, blocking is there and no tripping command is initiated. So, this we have discussed.

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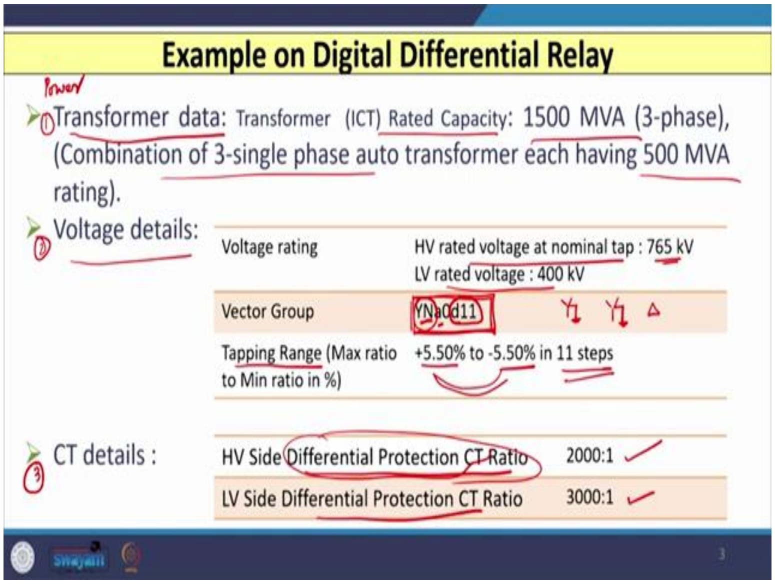

Now, with all our discussion, let us consider one example on digital differential relay. So, if you are let us say in charge of any junior engineer or deputy engineer of any substation, and if any digital relay is available or installed by some of the manufacturer, then what data you need to require or what data you need to input to this digital differential relay and how the settings of this relay that can be carried out.

So, if I consider the data then first we need the power transformer data. So, that data we need to enter to the relay. So, let us assume that the transformer available is ICT, that is interconnecting transformer or auto transformer and it is 3-phase rating is 1500 MVA, when we look at in the field auto transformer then normally we used bank of 3 single phase auto transformer.

So, each has let us say a rating of 500 MVA. Now regarding the voltage details so if I consider the voltage details the voltage rating, that is HV rated voltage assuming that tappings are available on HV side. So, rated voltage of HV winding at nominal tap let us say that is 765 kV, the LV rated voltage that is 400 kV and the vector group that is shown as YNa0d11.

So, here this ICT or auto transformer which we are considering this has 3 windings so it is 3 winding transformer. So, it is HV winding is star connected, LV winding is also star connected and the third winding which is tertiary winding that is delta connected. So, here when you enter the vector group, in that case, you can see that this neutral point of star is grounded for both HV and LV.

So, here only I have given in the vector group either HV or LV winding because both are same in case of auto transformer and then a stands for auto transformer and then you have d11, that is related to the delta or the tertiary winding. However, we are not interested in the third winding that is delta winding. Next is the tapping range.

So, normally tappings are provided on HV side, because we know that the magnitude of current is lower compared to the LV side. And so, when we change the tap then the arcing that can be easily avoided, that is why tappings are provided on HV side. So, in this case, the maximum ratio of tappings that is plus 5.5 percent and the lowest tap that is minus 5.5 percent.

So, the tappings will vary from plus or minus 5.5 percent and the total taps are 11 taps available. The third one is the CT details. So, if we consider the current transformer ratio, then HV side differential protection CT ratio is 2000/1 ampere and LV side differential protection CT ratio that is 3000/1 ampere.

So, here you can see that I have mentioned HV side differential protection CT ratio because normally for differential protection in case of power transformer separate CTs are used on HV and LV side. If I go for over current and earth fault protection also in case of power transformer as a backup, then also we can go for the another CT that is why I have mentioned here HV side differential protection CT ratio and similarly LV side differential protection CT ratio.

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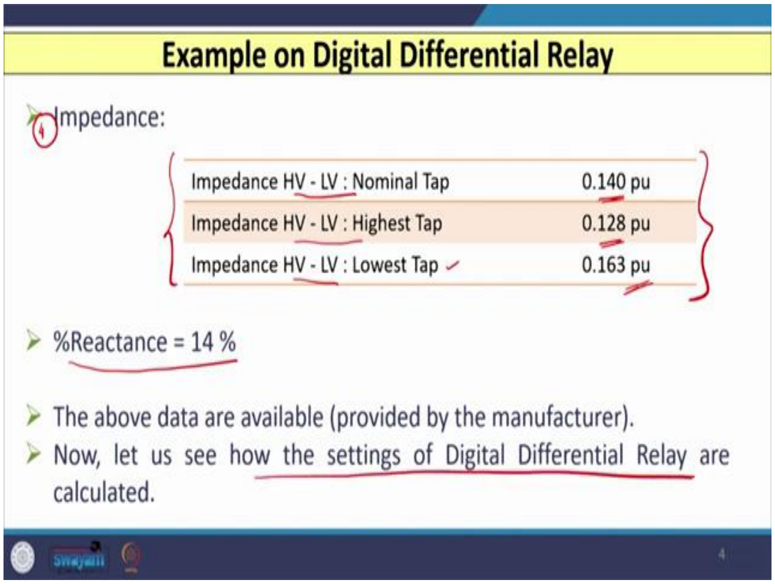

Next is the impedance details. So, if I consider the values of impedance, then we need the impedance of HV to LV at Nominal Tap let us say it is 0.14 unit we also need at impedance from HV to LV for Highest Tap let us say that is 0.128 per unit and we have HV to LV impedance for lowest Tap let us say that is 0.163 units. So, this data are normally provided or available, when you procure the transformer.

So transformer manufacturer has to provide this data, the percentage reactance let us say that is 14 percent this is also provided by transformer manufacturer. So, as the above data are available usually provided by the manufacturer. So, now with this data, let us see how the settings of digital differential relays are calculated.

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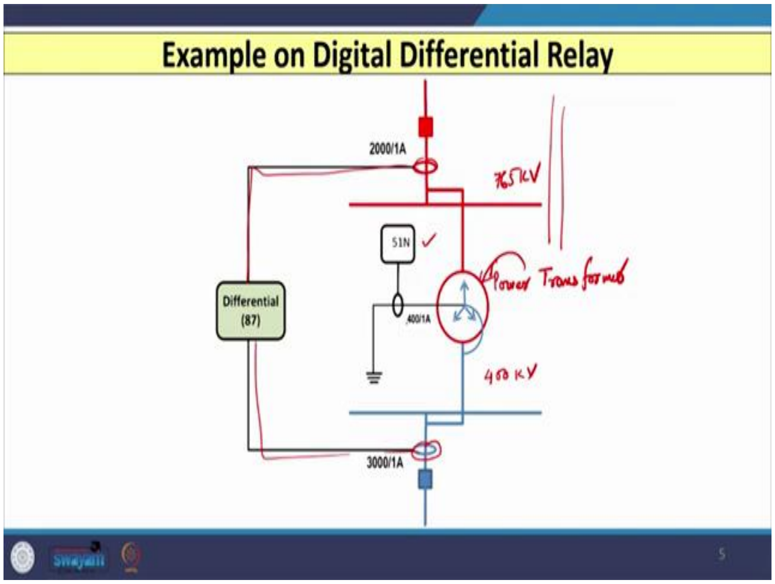

So whatever transformer I have shown that is ICT it has 3 windings HV and LV both are star connected and the third is the delta winding that is tertiary winding. So, I have shown here in the diagram only the HV and LV winding, so, this is our power transformer. So, you can see (as shown in above slide) that this power transformer that is under consideration and you can see that on HV side that is shown by red color (as shown in above slide).

So, this is your 765 kV side HV side and the other side with blue color that is LV side that is of 400 kV and on each side you can see I have provided the CT on HV side and the CT on LV side also here and that is connected to the differential relay. So, the output of this CT and output of the CTs, they are given to the differential relay.

Of course, this transformer has several other protection functions also. So, if I have let us say over current and earth fault protection, let us say 51N then we need separate city as I told you earlier.

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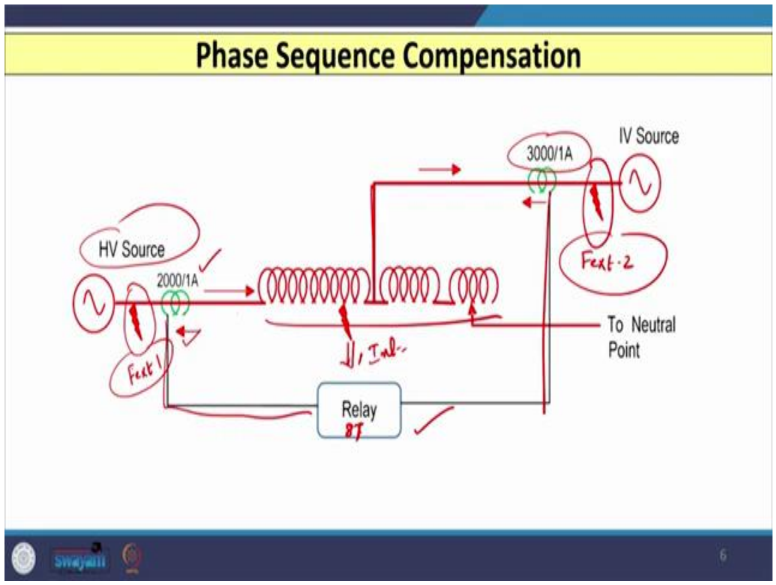

Now, if I consider one of the phase of this ICT or auto transformer, then you can see (as shown in above slide) that I have the winding like this and in between I have taken the tappings. So, I have the HV source on one side where the CT ratio on HV side that is 765 kV side is 2000/1 ampere and I have the another CT on LV side where the CT ratio is 3000/1 ampere and the output of this LV side CT and output of HV side CTs, that is given to the differential relay that is relay 87 and you can see (as shown in above slide) that I have also shown the three important fault points, one is this point, another is this point and the third one that is this point. So, these two points let us say these are the external fault 1, this is the external fault 2 and this is your internal fault.

So if any fault occurs inside the winding on this right hand side of this HVCT and left hand side of this LVCT those faults are internal faults and that can be cleared or detected by this differential relay. Any fault other than this, let us say this fault external fault 2. And this external fault 1 may be on HV side or on LV side. These are the external faults and these faults are not detected by this relay 87 R differential relay. So, this relay should remain stable in this situation. And this condition we need to check.

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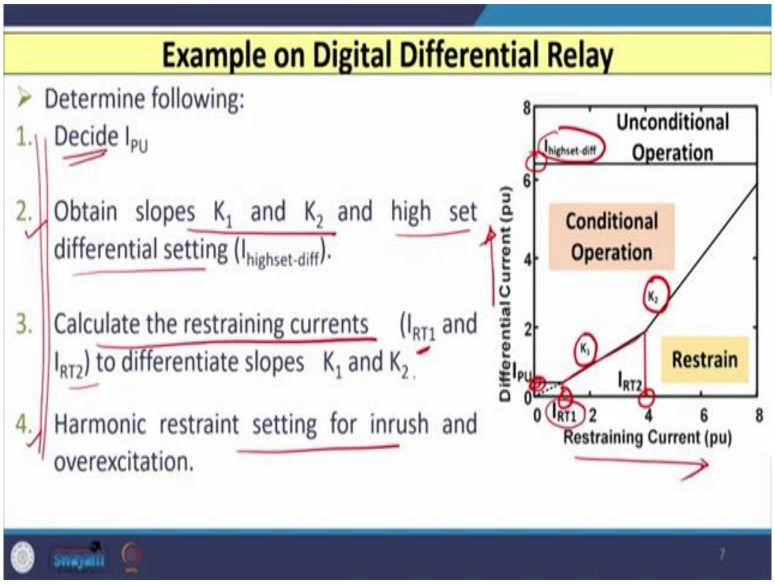

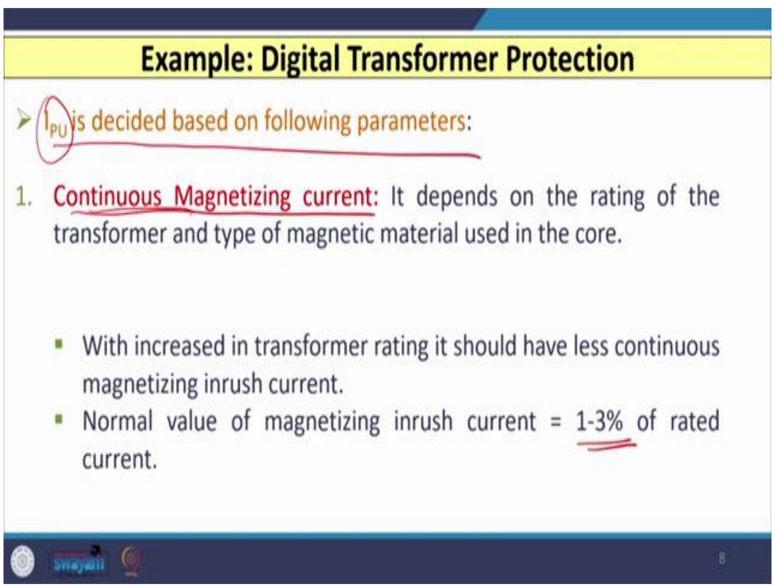

So, now, with this background, let us see, we need to determine the following things. So, I have shown here differential relay characteristic, so, you can see on x-axis I have the restraining current in per unit and on the y-axis I have the differential current or operating current in per unit. Now, here the first thing we need to decide is the I per unit.

So, this you can see on the y- axis this point, we need to find out that what is the setting of I per unit? And what parameters we need to consider, when we decide the setting of I per unit which is known as initial threshold. The second thing is we need to obtain the slopes that is we are assuming dual slope characteristic.

So, we need to calculate the value of the two slopes that is K_1 and K_2 this is your first slope and this is your second slope (as shown in above slide). So, you need to calculate the value of K_1 and K_2 and then you have to also see the value of high set differential setting that is I high set differential. So, this value which is on x-axis. So, this also you need to determine or calculate.

The third thing is we need to also calculate the restraining currents which is given on x-axis that is I_{RT1} that is this point that is I_{RT1} and the I_{RT2} that is this point (as shown in above slide), we need to determine these two points. So, that the differentiation of the slopes between K_1 and K_2 that can be carried out and the fourth very important point because we have discussed the harmonic restraint or harmonic blocking.

So, we need to also determine or we need to also give as an input, what is the setting for inrush and what is the setting for over excitation. So, that relay should not operate in case of inrush or in case of over excitation condition. So, we need to calculate these four things. So, we have to first assume these four values four settings that is 1, 2, 3, 4.

And then we will cross check with the given conditions that whether this relay will operate or not in normal or any external or any other abnormal conditions, if relay should not operate, then we can say that these settings whatever we have done in the digital relay, those are correct. Now, with this background, let us see first how we can have or decide the value of I per unit.

So, as I told you that this point I per unit, we have to decide, and that depends on three important parameters. The first parameter is the continuous magnetizing current. So, we know that the normally magnetizing current of any power transformer that depends on rating of the transformer and what type of magnetic material we have used in the core of the power transformer and as we increase the transformer rating, then we can say that the less continuous magnetizing inrush current that can be observed and normal value of magnetizing inrush current that is 1 to 3 percent of the rated current. So, this when we decide the setting of I_{PU}, this we need to consider.

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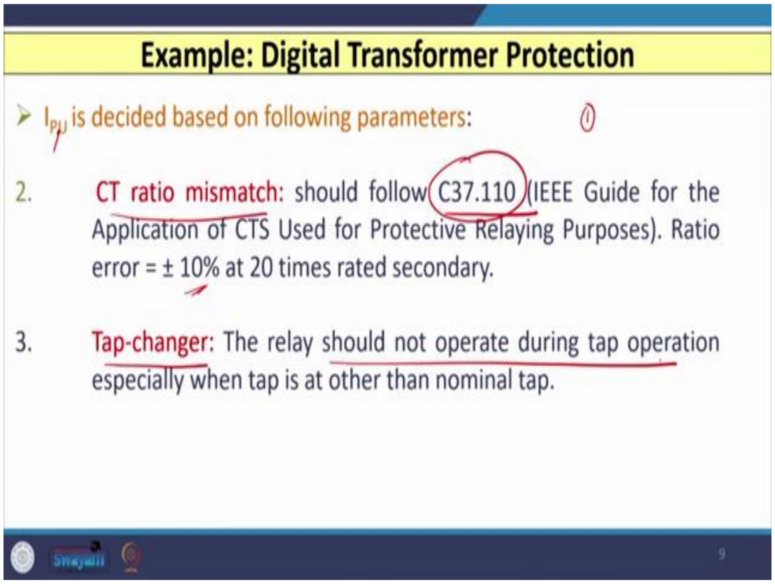

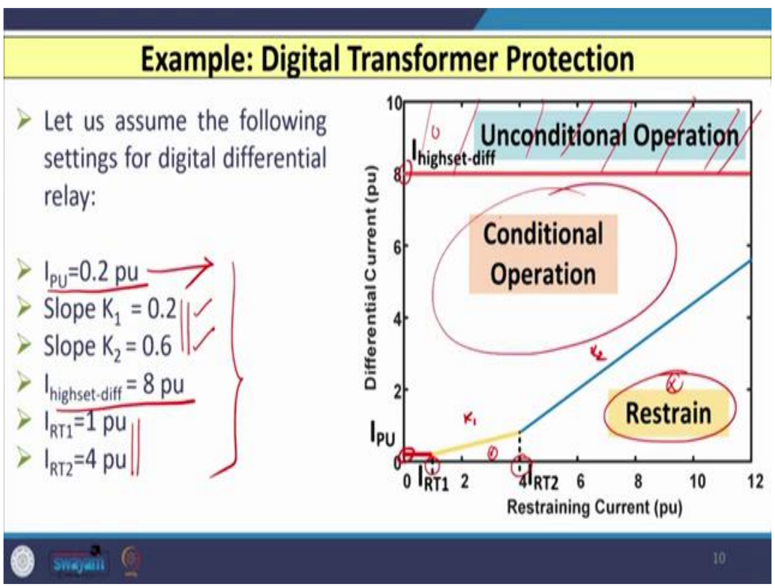

The other two important points that is the CT ratio mismatch that also we need to consider. So, when we talk about CT ratio mismatch, we need to consider the IEEE guide C37.110, and this guide is for the application of current transformers used for protective relay, and in this guide, it is clearly mentioned that the ratio error that should be plus or minus 10 percent at 20 times the rated secondary current.

So, if let us say your secondary current is 1 ampere, and if your current is 20 times the 1 ampere so 20 ampere, then the ratio error should not exceed plus or minus 10 percent as per this standard.

So, based on this also you need to consider the value of I per unit and the third thing that is the tap changer.

So, at what tap the transformer is operating, whether it is at nominal tap or maybe highest tap or maybe the lowest tap. So, whatever setting is relay should not operate in this condition. So, considering all these three parameters we have to decide or we have to initially assume are set by experience the value of I per unit.

So, with the experience normally most of the utility. They will assume the following values for I per unit normally the utility or manufacturer will suggest the value of I_{PU} that is 0.2 per unit. So, this value is 0.2 per unit, the 2 slopes assuming dual slope characteristic that is used. So, K_1 that is assumed as 0.2 and K_2 that is considered as 0.6.

So, you have the K_1 and K_2 these two values you need to consider. So, this is your K_1 and K_2 that you need to assume. The highset differential current you need to assume and here I have considered is 8 per unit and the two restraining currents I_{RT1} and I_{RT2} that I have assumed as 1 per unit and 4 per unit.

Now, we have assumed these values because these are the normal values suggested by manufacturer or maybe assumed by most of the utilities in case of digital differential relay. Now, with these values, our strategies, we will consider different cases and we will see that whether my relay will remain stable or not, if relay remain stable that means relay should not operate and then we can say that these settings are correct.

Now, before we move for the verification few things we need to consider with reference to this characteristic, you see that the operating condition is when your operating point falls above this characteristic. So, this is your operating region any operating point below this characteristic that is the restraining region or blocking region.

So, whenever any mismatch is there maybe because of CT ratio or maybe because of the unidentical CT saturation characteristic or maybe because of tap changing mechanism, then the current or the operating point should fall somewhere here, when you have let us say saturation of CT in case of heavy through fault or external fault, then your point should be again lie in this region. So, that relay should not operate and that is what we want. And in case of any internal fault condition, the immediately your point will move in this region.

So, there is no waiting period and the relay should immediately trip and the respective circuit breaker will be operated. However, one typical case is there, where that is the magnetizing inrush condition. So, in case of inrush the magnitude of current is very high. So, you will have the operating point will be in conditional operation region that falls under the operating region.

So, in that case again we will go for the checking of second harmonic or fifth harmonic in case of over excitation and then we will decide whether the percentage of harmonics in any one of the phases that exceeds threshold or not, if it is exceeds then the tripping is restrained, that means, blocking is initiated no tripping is there. And if it is not there, then again tripping is finally given this is very important point we need to consider. Now, with this assumed setting, let us verify, whether these settings are correct or not by taking different cases.

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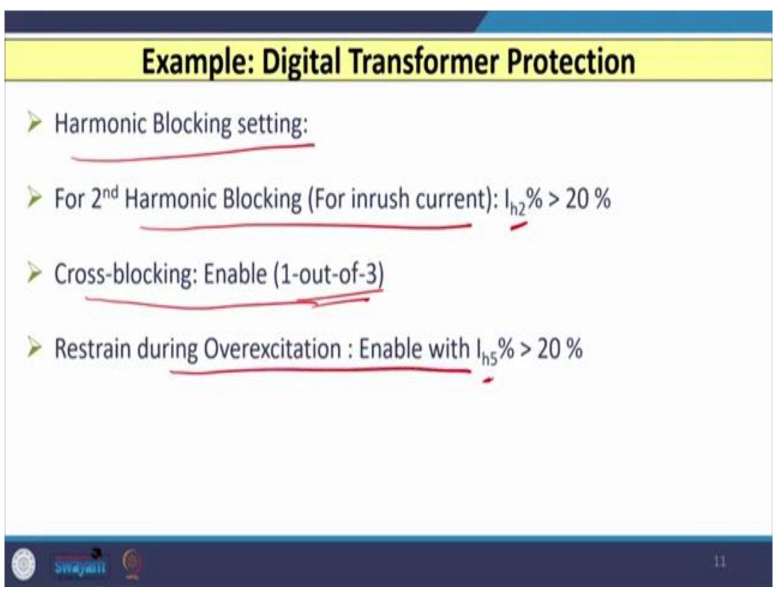

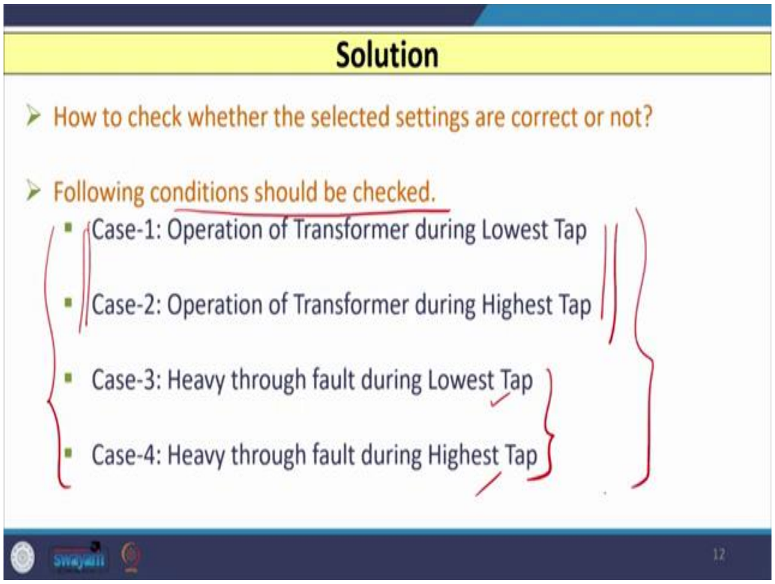

So, before we go that the harmonic settings are also important. So, what we have assume is that for inrush detection, second harmonic blocking we have assumed that the second harmonic content with reference to fundamental that should be 20 percent. So, if it exceeds 20 percent, then inrush is detected in digital relay most of the manufacturers they will also give the facility that whether you want to enable the cross blocking feature or not.

If you say yes then you can go for different cross blocking feature say 2 out of 3 or 1 out of 3, but as we have discussed earlier that 1 out of 3, blocking is widely used. So, if any one of the phases if the percentage of second harmonic exceeded certain value then the blocking is there, no tripping is given and for over excitation condition, we assume that percentage of fifth harmonic current that should be also 20 percent.

So, if we to exceed 20 percent, then over excitation condition is detected and no tripping is initiated. Now, whatever settings we have assumed to cross check or verify that we have to consider different cases. So, let us consider these four different cases one by one. So, the first two case you can see here that is related to the operation of transformer on lowest tap and second case is related to the operation of transformer on highest tap and the third and fourth case that is related to heavy through faults. So, when external fault occurs during lowest tap and highest tap, then whether relay should be able to operate or not. So, in all the 4 cases relay should not operate with whatever settings we have assumed.

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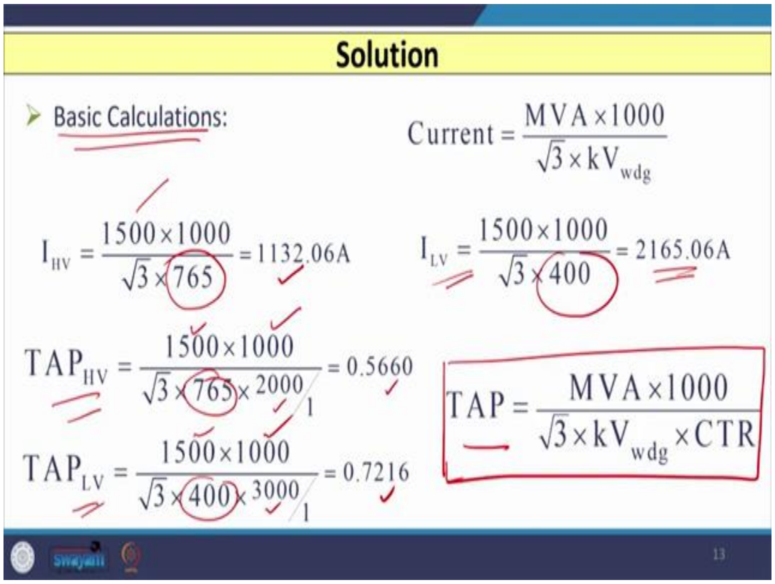

So, let us consider the first case now, before we go to the first case, let us do some basic calculations. So, we know that the MVA rating of the transformer is given that is 1500 MVA and the HV side the voltage rating is 765 kV. So, you can easily calculate the full load current on HV side. So, you have

$$I_{HV} = \frac{1500 \times 1000}{\sqrt{3} \times 765} = 1132.06A$$

So, the full load current on HV side comes out to be 1132.06 ampere same way you can also calculate the current on LV side, the only change is this voltage instead of 765 kV it is 400 kV

$$I_{LV} = \frac{1500 \times 1000}{\sqrt{3} \times 400} = 2165.06A$$

So, the current will be 2165.06. Now, when we consider the 3 cases, that is the zero sequence compensation tap compensation, that is magnitude compensation and phase sequence compensation, we have discussed that the equation of tap that is given by this.

$$TAP = \frac{MVA \times 1000}{\sqrt{3} \times kV_{wdg} \times CTR}$$

So, using that tap equation for magnitude compensation, let us calculate the tap on HV side and tap on LV side.

$$TAP_{HV} = \frac{1500 \times 1000}{\sqrt{3} \times 765 \times \frac{2000}{1}} = 0.5660$$

$$TAP_{LV} = \frac{1500 \times 1000}{\sqrt{3} \times 400 \times \frac{3000}{1}} = 0.7216$$

So, this four values current on HV and LV sides and tap on HV and LV sides we will use in our all the four cases.

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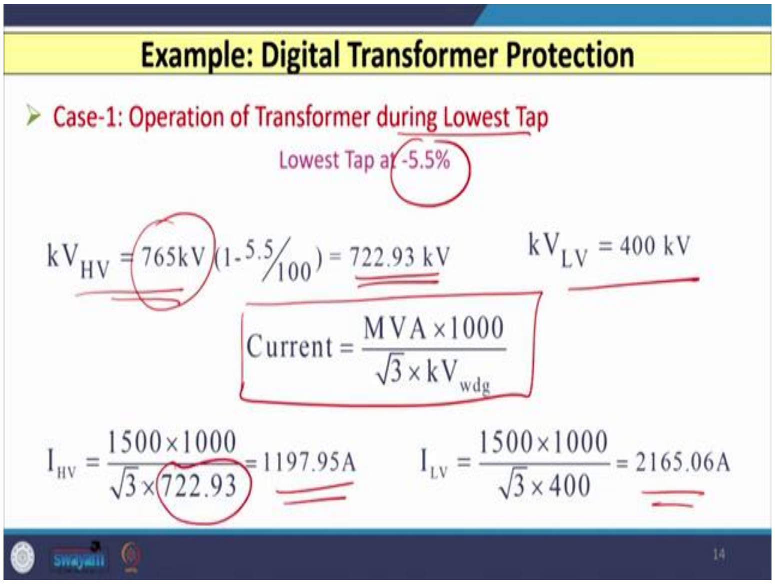

Now, let us consider the first case operation of transformer during Lowest Tap. So, lowest tap as I told you it is minus 5.5 percent. So, the voltage on HV side because more as the tappings are provided on HV side. So, voltage on HV side that will change. So, let us calculate that voltage, so, kV on HV side $kV_{HV} = 765kV\,(1-\frac{5.5}{100}) = 722.93\ kV$

So, the new voltage comes out to be 722.93 kV, your LV side voltage remains as it is there is no change. So, you can now calculate the current using this equation that is

$$\text{Current} = \frac{\text{MVA} \times 1000}{\sqrt{3} \times kV_{wdg}}$$

So, if I put the value of I_{HV} and I_{LV} then we will have the current these two values.

$$I_{HV} = \frac{1500 \times 1000}{\sqrt{3} \times 722.93} = 1197.95A$$

$$I_{LV} = \frac{1500 \times 1000}{\sqrt{3} \times 400} = 2165.06A$$

So, the only difference here you can see that is this voltage that will change and that is on HV side and this voltage that is on LV side. So, you will have these two currents. Now, these two currents we need to again transform on the secondary side using CT ratio on HV side and CT ratio on LV side.

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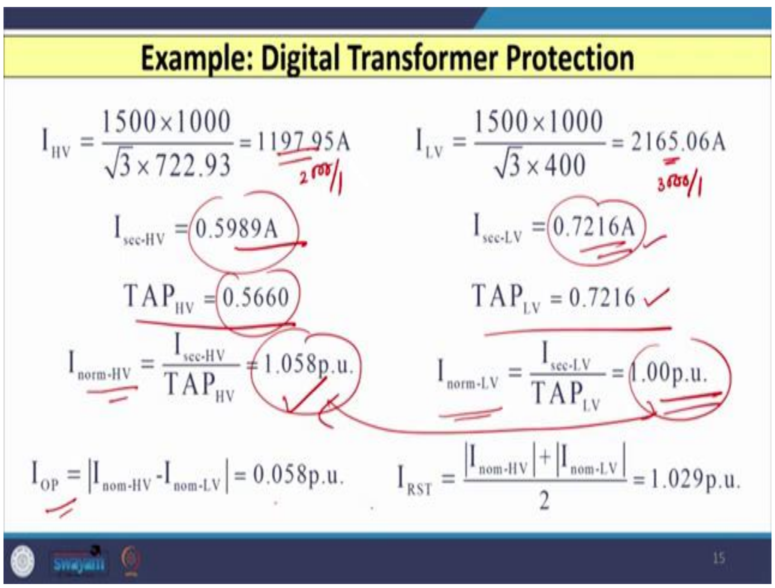

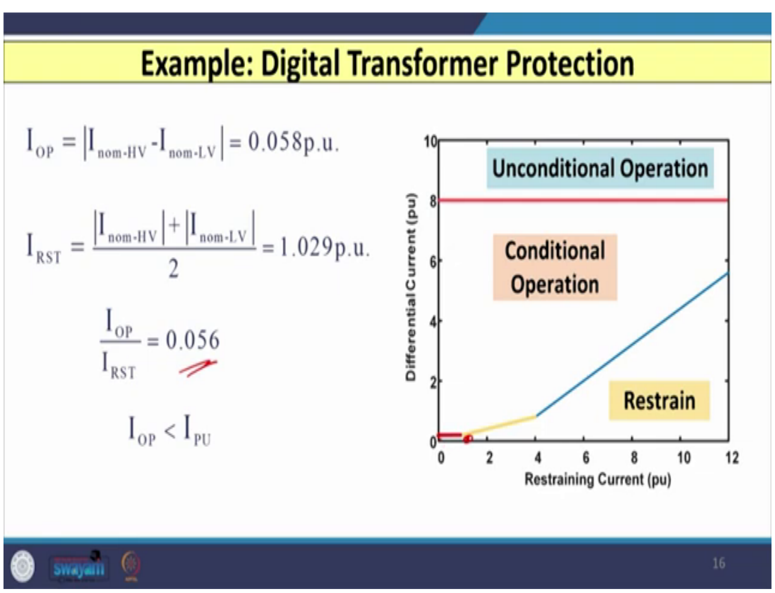

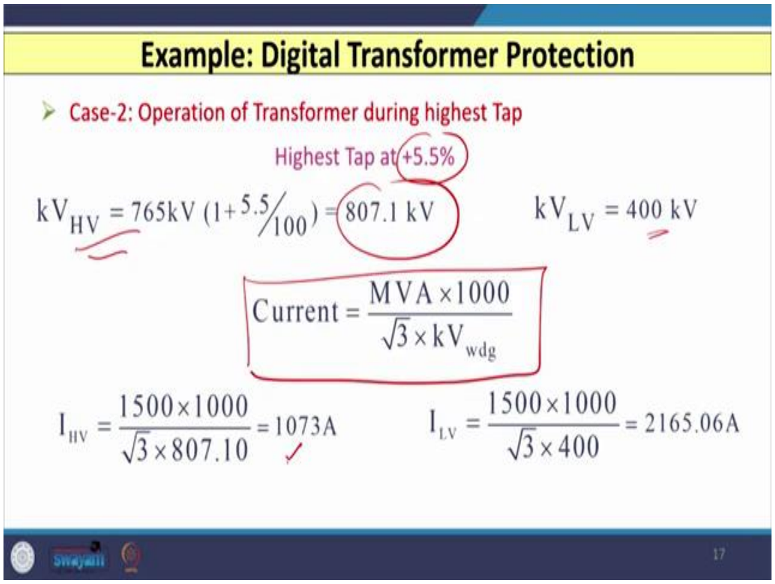

So, this current is on HV side and you know the CT ratio is 2000 by 1. So, secondary side you will have this current and same way on LV side you have the CT ratio that is 3000 by 1. So, you have the current that is available on secondary side on LV side of winding of the transformer that is this one. Now as the secondary currents are available the TAP_{HV} and TAP_{LV} also we have calculated. So, we have to normalize it. So, I normalize on HV side that is the I secondary HV that is this value divided by this value. So, you will have this value and same way on this side I normalize on LV side that is also you can have the, this value divided by this so, you will have 1 per unit.

$$I_{HV} = \frac{1500 \times 1000}{\sqrt{3} \times 722.93} = 1197.95A \qquad I_{LV} = \frac{1500 \times 1000}{\sqrt{3} \times 400} = 2165.06A$$

$$I_{sec\text{-}HV} = 0.5989A \qquad I_{sec\text{-}LV} = 0.7216A$$

$$TAP_{HV} = 0.5660 \qquad TAP_{LV} = 0.7216$$

$$I_{norm\text{-}HV} = \frac{I_{sec\text{-}HV}}{TAP_{HV}} = 1.058p.u. \qquad I_{norm\text{-}LV} = \frac{I_{sec\text{-}LV}}{TAP_{LV}} = 1.00p.u.$$

$$I_{OP} = |I_{nom\text{-}HV} - I_{nom\text{-}LV}| = 0.058p.u.$$

$$I_{RST} = \frac{|I_{nom\text{-}HV}| + |I_{nom\text{-}LV}|}{2} = 1.029p.u.$$

So, you can see that on LV side you will have the 1 per unit but on HV side, the normalized value of current that is not 1 per unit. So, that is why this two difference you will have the operating current that is not 0, but it is some 0.058 per unit and restraining current if you calculate, then you will have 1.029 per unit and if I calculate the ratio of operating current to restraining current that comes out to be 0.056.

So, operating point is 0.5. So, this is my I_{PU} 0.2. So, that will be very small 0.05 and your restraining is almost 1. So, this is 2, so, almost your point will be somewhere here below this characteristic. So, relay should not operate and relay not operating in this case. Now, if I consider the again the operation of transformer on highest tap, then my highest tap will be 5.5 percent plus, so, my kV voltage 1 plus 5.5.

So, my updated voltage is 807.1 kV my LV side voltage remains same, you can calculate the value of current on both HV and LV side. So, HV side current is 1073 and LV side it is 2165.

$$I_{HV} = \frac{1500 \times 1000}{\sqrt{3} \times 722.93} = 1197.95A$$

$$I_{LV} = \frac{1500 \times 1000}{\sqrt{3} \times 400} = 2165.06A$$

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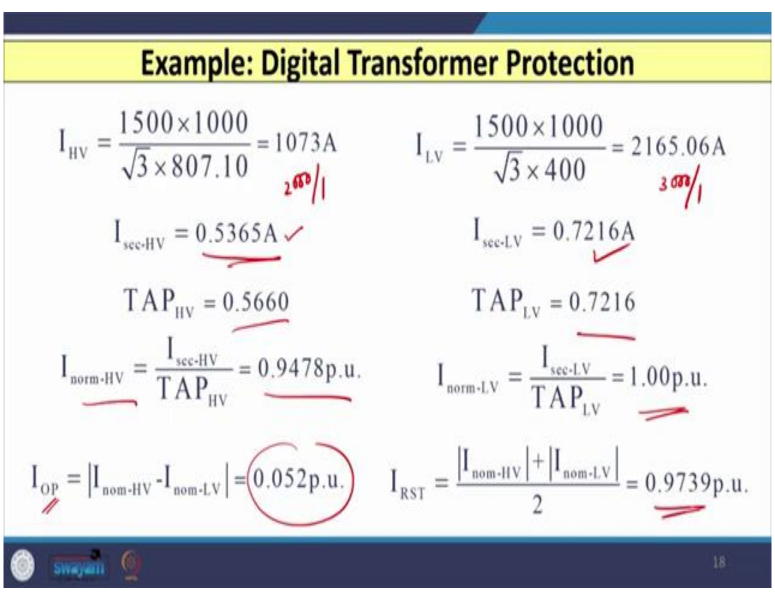

This current you can again transform by CT ratio on secondary side. So, that is 0.5365. Assuming 2000 by 1 ampere CT on HV side and on this side you have 3000 by 1 ampere so, 1073 by 2000 into 1 you will have this current and on this side 2165.06 by 3000 into 1 so, you will have this current. Tap HV and Tap LV we have already calculated.

$$I_{sec\text{-}HV} = 0.5989A \qquad I_{sec\text{-}LV} = 0.7216A$$

$$TAP_{HV} = 0.5660 \qquad TAP_{LV} = 0.7216$$

So, normalized current on HV side is 0.9478 and normalized current on LV side is again 1 per unit. So, as both are not 1, the operating current is not 0, but you will have some significant value same way restraining current is also there.

$$I_{norm\text{-}HV} = \frac{I_{sec\text{-}HV}}{TAP_{HV}} = 1.058\text{p.u.}$$

$$I_{norm\text{-}LV} = \frac{I_{sec\text{-}LV}}{TAP_{LV}} = 1.00\text{p.u}$$

$$I_{OP} = |I_{nom\text{-}HV} - I_{nom\text{-}LV}| = 0.058\text{p.u.}$$

$$I_{RST} = \frac{|I_{nom\text{-}HV}| + |I_{nom\text{-}LV}|}{2} = 1.029\text{p.u.}$$

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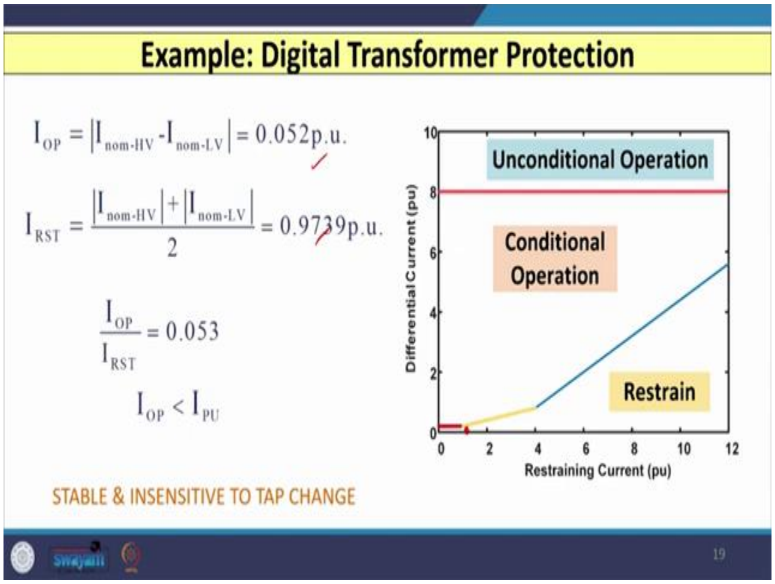

But still you can see that these two values the 0.05 and 0.97. So, again your operating point will be coming like this somewhere here below this characteristic and relay remains stable (as shown in above slide). So, whatever settings we have done, those are accurate for these two cases. Now, let us consider the third case when we consider heavy through fault with lowest tap.

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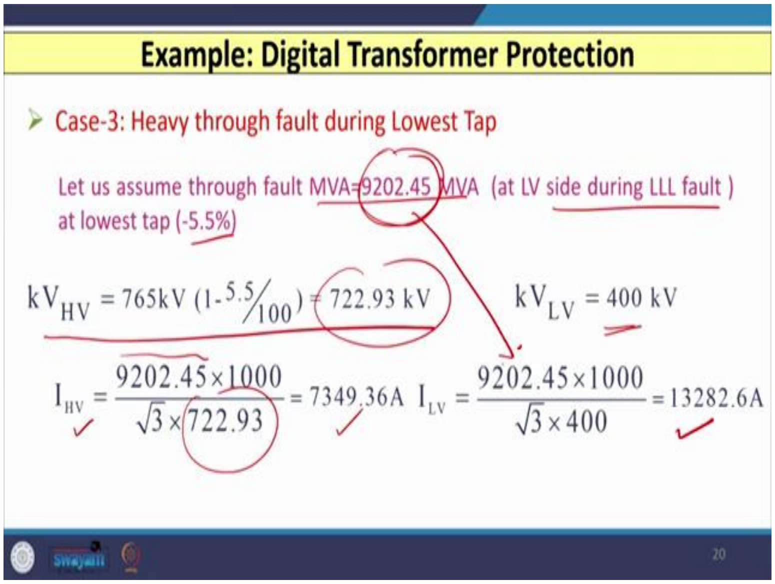

So, let us assume that in case of the external fault or heavy through fault, MVA value is 9202.45 MVA assuming LLL fault on LV side with lowest tap that is minus 5.5 percent. So, for lowest tap we have already calculated the HV voltage on HV side that is 722.93 LV side voltage remains as it is 400 kV.

$$kV_{HV} = 765kV\ (1-\frac{5.5}{100}) = 722.93\ kV$$

So, with this let us calculate the current on HV side with this MVA value that is 9202 and with this voltage because my tap is on lowest side. So, this voltage so, you will have the current on HV side is this 7349.36 ampere and on similarly on LV side you have this current with this MVA value.

$$I_{HV} = \frac{9202.45 \times 1000}{\sqrt{3} \times 722.93} = 7349.36A$$

$$I_{LV} = \frac{9202.45 \times 1000}{\sqrt{3} \times 400} = 13282.6A$$

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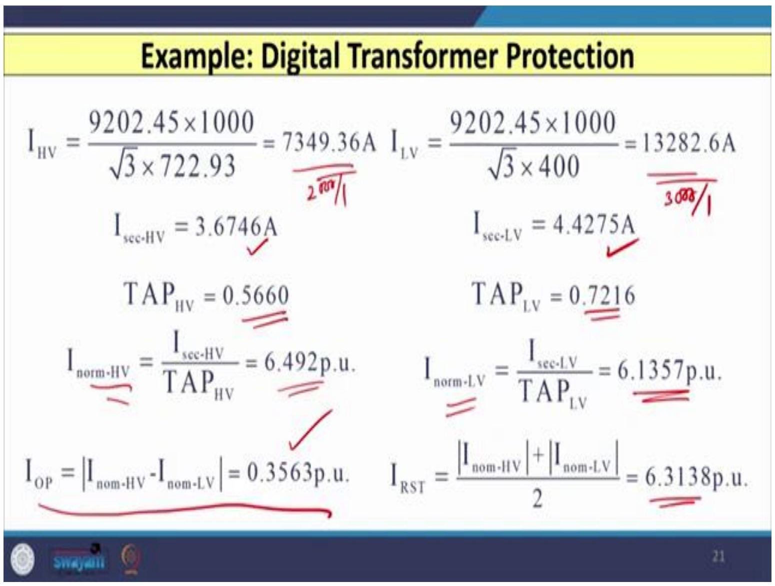

Now, with this two currents let us again transform on CT secondary side. So, 2000/1 and 3000 by 1 CT ratio. So, you will have the currents that is 3.6746 and 4.4275

$$I_{sec\text{-}HV} = 3.6746A \qquad I_{sec\text{-}LV} = 4.4275A$$

$$TAP_{HV} = 0.5660 \qquad TAP_{LV} = 0.7216$$

$$I_{norm\text{-}HV} = \frac{I_{sec\text{-}HV}}{TAP_{HV}} = 6.492p.u.$$

$$I_{norm\text{-}LV} = \frac{I_{sec\text{-}LV}}{TAP_{LV}} = 6.1357p.u.$$

$$I_{OP} = |I_{nom\text{-}HV} - I_{nom\text{-}LV}| = 0.3563p.u.$$

$$I_{RST} = \frac{|I_{nom\text{-}HV}| + |I_{nom\text{-}LV}|}{2} = 6.3138p.u.$$

We have already calculated tap on HV and LV side. So, we can have the normalized current on HV side that comes out to be 6.492 and normalized current on LV side that comes out to be 6.1357. So, if you take the operating current then it is 0.3563 and your restraining current is again 6.3.

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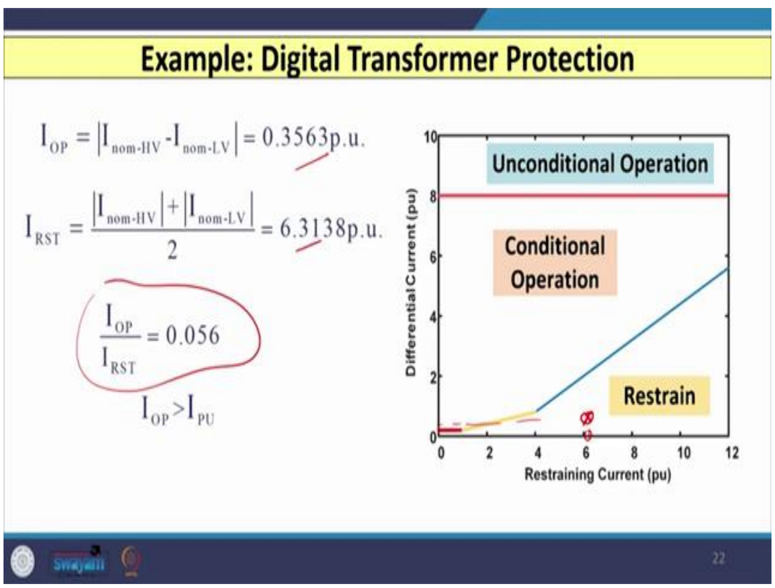

So, with this two values, if you calculate the ratio the ratio comes out to be 0.056.

$$\frac{I_{OP}}{I_{RST}} = 0.056$$

So, with this operating and restraining value if you put it on this differential characteristic, this is 0.2. So, 0.3 will be somewhere here and your restraining current is 6.3. So, that is roughly around somewhere here in this region (as shown in above slide). So, your point will be somewhere here it is in second slope below the characteristic in restraining region. So, again the relay remains stable it should not operate.

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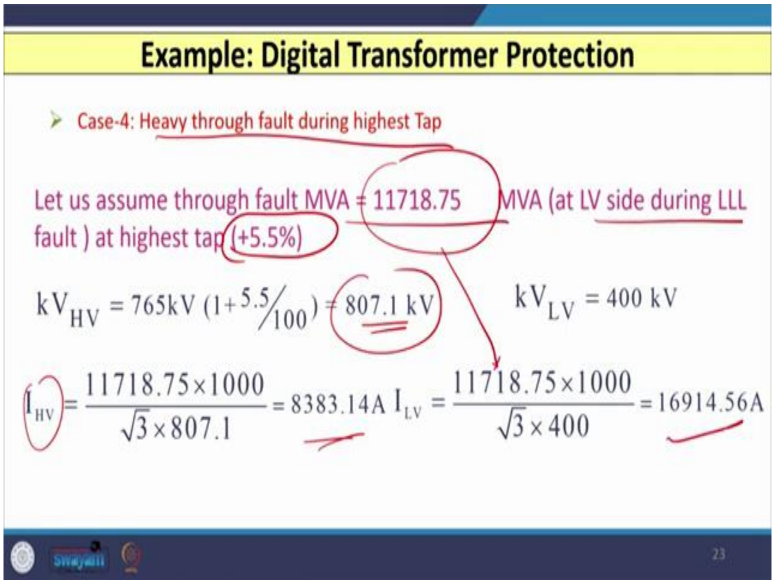

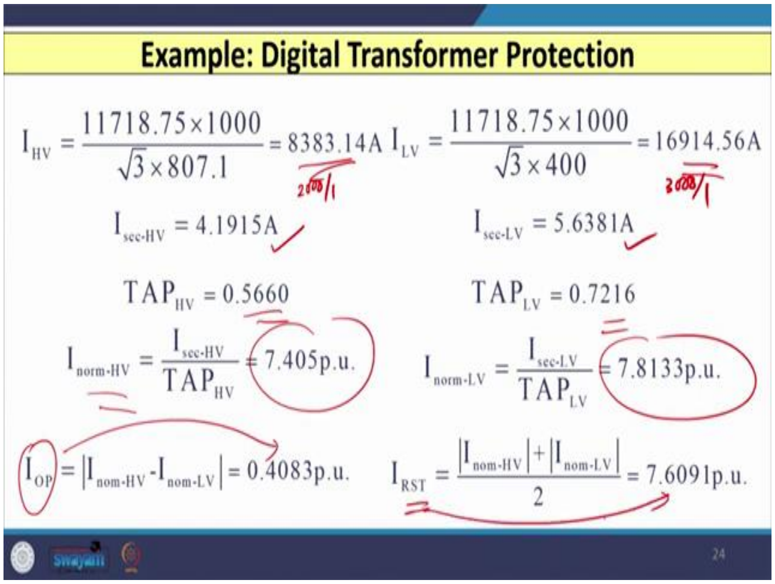

Similarly if I consider the same heavy through fault on highest tap let us say we assume it is 11718 MVA assuming the LLL fault on the LV side with highest tap plus 5.5 percent. So, only change is voltage and this MVA. So, with this MVA and this voltage let us calculate the current on HV side and your current on LV side with this MVA value that is this.

$$I_{HV} = \frac{11718.45 \times 1000}{\sqrt{3} \times 807.1} = 8383.14A$$

$$I_{LV} = \frac{11718.45 \times 1000}{\sqrt{3} \times 400} = 16914.56A$$

And if I transform these two current with CT ratio 2000 by 1 and 3000 by 1, then you will have the current on secondary side LV and HV that is this value, we have already calculated tap on HV and LV. So, we will have normalized value of current on HV side that is 7.4 per unit and normalized value of LV side current that is 7.8 per unit. So, your operating current comes out to be 0.4 and restraining current comes out to be 7.6.

$I_{sec\text{-}HV} = 4.1915A$ $\quad\quad$ $I_{sec\text{-}LV} = 5.6381A$

$TAP_{HV} = 0.5660$ $\quad\quad$ $TAP_{LV} = 0.7216$

$$I_{norm\text{-}HV} = \frac{I_{sec\text{-}HV}}{TAP_{HV}} = 7.405p.u.$$

$$I_{norm\text{-}LV} = \frac{I_{sec\text{-}LV}}{TAP_{LV}} = 7.8133p.u.$$

$$I_{OP} = |I_{nom\text{-}HV} - I_{nom\text{-}LV}| = 0.4083p.u.$$

$$I_{RST} = \frac{|I_{nom\text{-}HV}| + |I_{nom\text{-}LV}|}{2} = 7.6091p.u.$$

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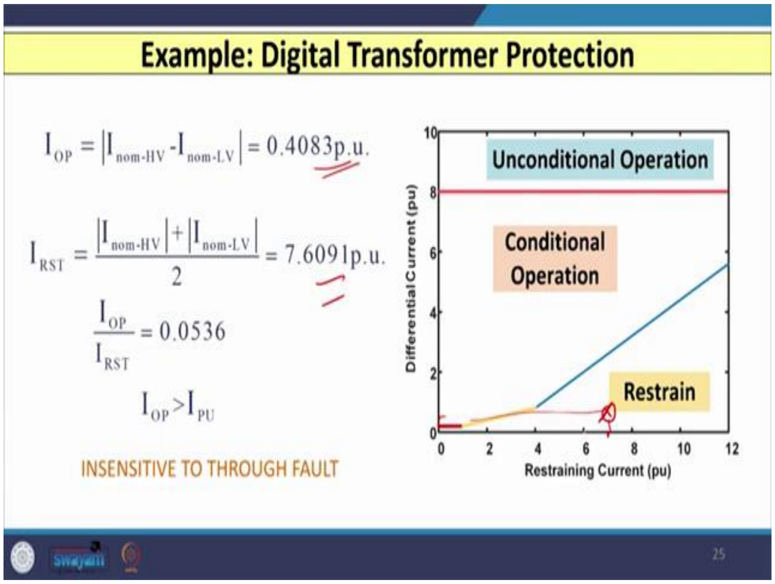

So, if you put these two points on the characteristic, then you will have the 0.4 roughly somewhere here and 7.6 so, again this is 7, so, it will be somewhere here. So, again your point will be somewhere here, so, the relay remains stable (as shown in above slide). So, whatever settings we have carried out those settings are such that the relay should not operate in either the transformer tap change condition or in case of external fault situation. However, if any internal fault is there and relay must operate.

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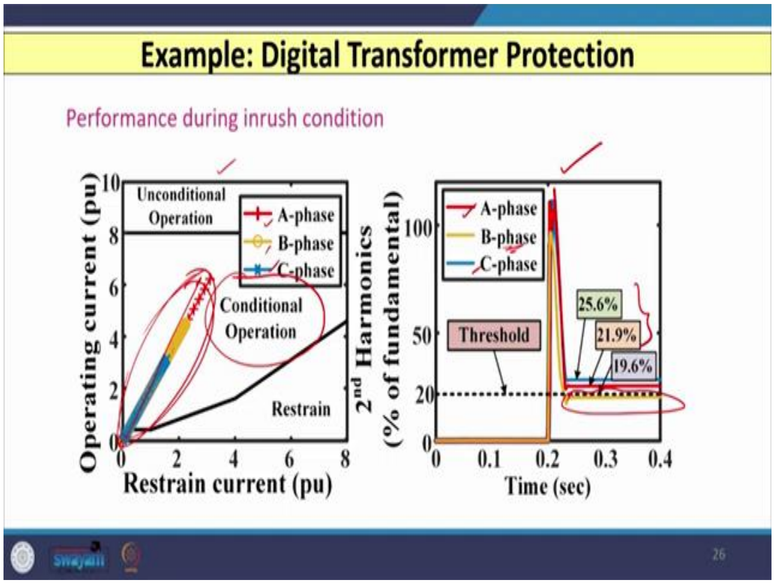

Now, with this background, I have shown the two important graphs you can see that I have shown the first graph, this is specifically during magnetizing inrush condition. So, in magnetizing inrush condition if you plot the characteristic on the differential relay characteristic for phase wise for all the 3 phases then definitely it will move from restraining region to the operating region you can see.

But here you can see that these points that is again in conditional operating region. So, here again our 87BL logic will come in picture (as shown in above slide). So, again the checking of second harmonic content that is percentage of second harmonic and percentage of fifth harmonic that both will be there. So, there will be a slight delay and after that if both the conditions are not there means they are below that particular threshold then the tripping command is initiated otherwise the tripping is blocked.

Here in this second graph you can see I have shown the percentage of second harmonics with reference to the fundamental and you can see that in phase wise I have shown so, for one of the phases (as shown in above slide) let us say for B-phase you can see here, this value falls below the threshold let us say 20 percent.

Whereas, for other 2-phases A and C phase the values that is be above 20 percent that is 25 and 21. But as we have used 1 out of 3 logic. So, if in any one of the phases if percentage of harmonics that exceeds 20 percent. Let us say for example, then the operation of the relay that is blocked. So, here relay is not going to operate in this situation and that is what we want.

So, in this lecture we have discussed regarding the example and if we have these different settings available in the digital relay starting from I per unit, these two slopes K1, K2. The third point is the two restraining currents I_{RT1} and I_{RT2} and the settings of percentage of harmonic current that is second for inrush and fifth for over excitation then how we can decide these settings. So, that relay should not operate in any of the external fault or any abnormal condition. However, relay must operate in case of internal fault condition. So, thank you.