Power System Protection and Switchgear
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Lecture 29
Protection of Generators-II

So, in the last class we were discussing about the Bias Differential Protection of the Generator. So, let us continue our discussion. So, as I told you, there are two coils in the bias differential protection scheme, one coil is known as operating coil.

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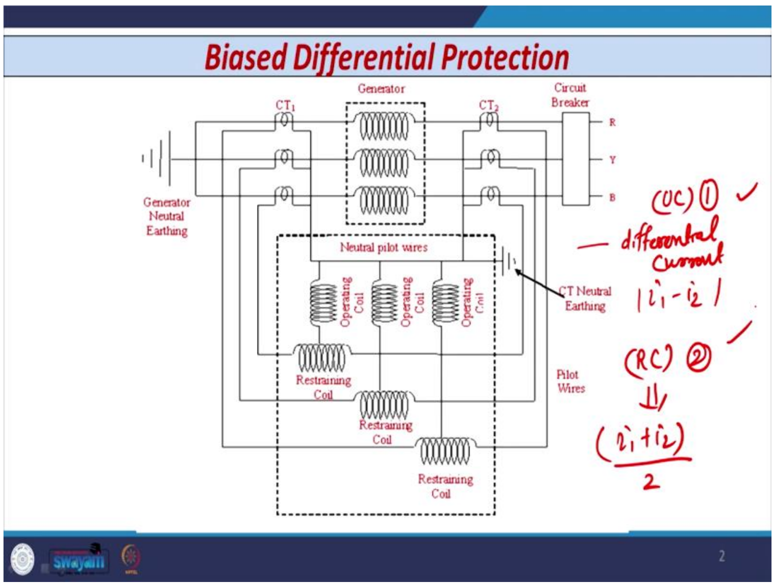

So, through operating coil, the current that flows that is the differential current and this differential current that is nothing but the difference of two currents. And that is the i1 minus i2. The other coil that is connected to the operating coil that is the restraining coil and this restraining coil is connected exactly at mid point with the operating coil.

So, the average restraining current that flows through the, this is the current that flows through the operating coil and the current that flows through to the restraining coil. That is the i1 plus i2 by 2, so based on these two points, there are two settings available in the bias differential protection scheme.

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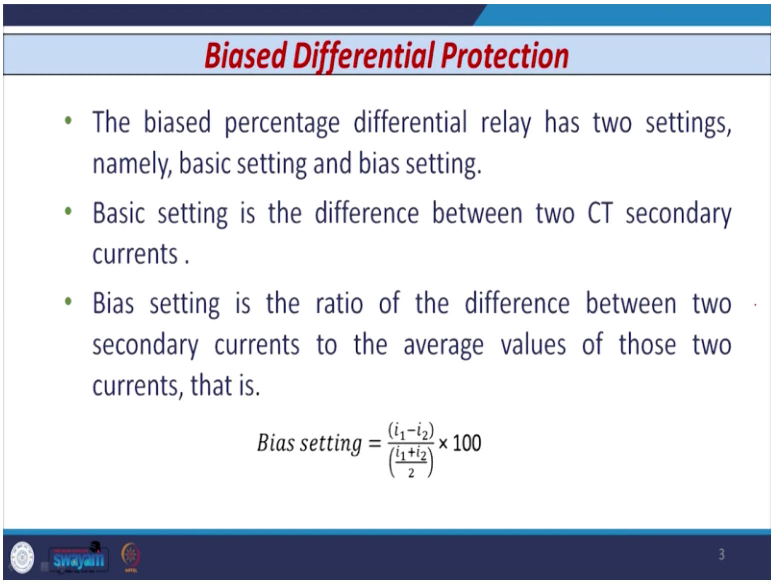

These setting are known as the one that is known as the basic setting or the sometimes that is also known as sensitivity setting.

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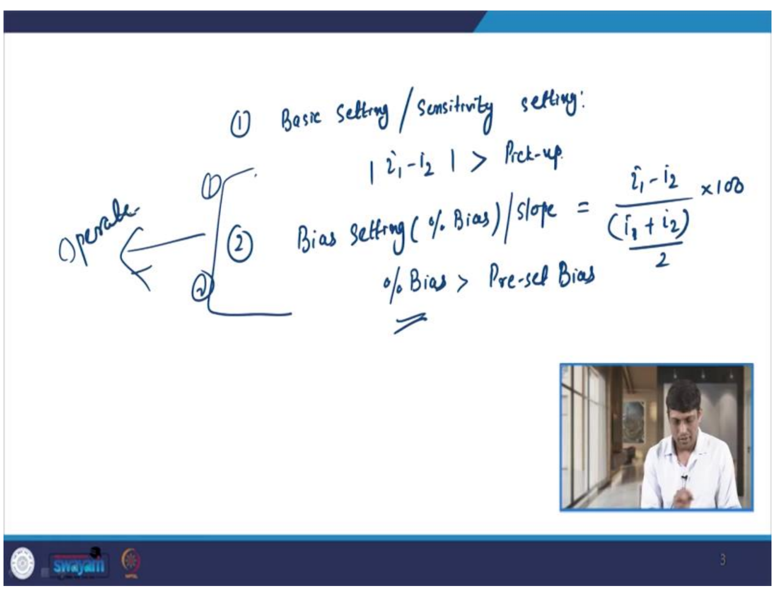

So, if I consider the first setting then that is known as the basic setting or the it is also known as the sensitivity setting. And this setting is nothing but the i1, difference of i1 minus i2 when it exceeds, some pickup then the relay operate and the second setting that is known as known as the bias setting.

Sometimes it is also known as percentage bias or sometimes it is also known as the slope setting then this is nothing but i1 minus i2 divide by i1 plus i2 by 2 into 100. So, if the bias setting exceeds some preset bias, so if percentage bias exceeds the preset bias then the relay operates. So, there is an n combination, n logic of this to, if both these conditions are satisfied then and then the relay gives a tripping command.

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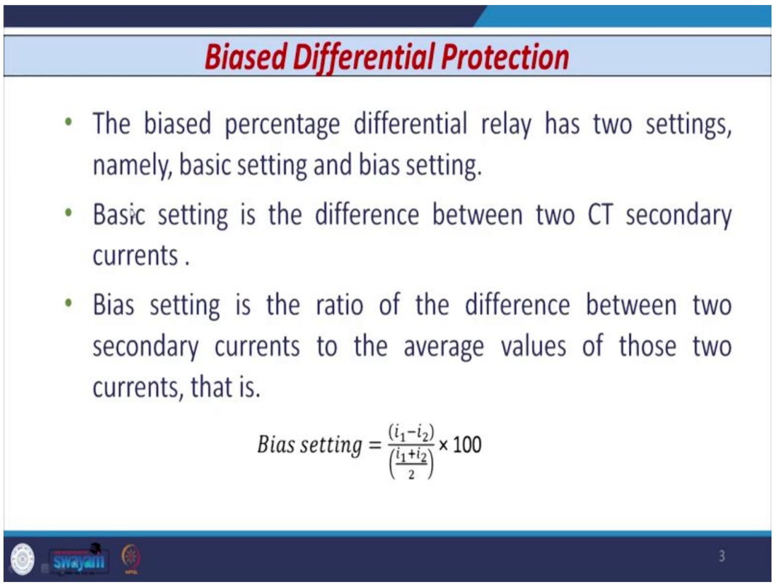

So, this is about the two settings of the bias differential protection scheme.

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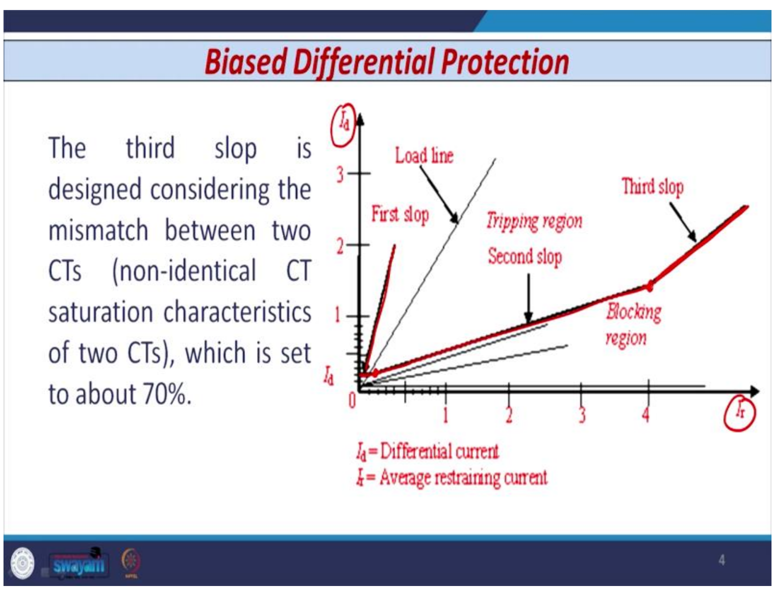

Now, let us see what is the characteristic of the bias differential protection scheme, as we have discussed in case of transformer protection, again the same differential characteristic in case of bias differential protection is plotted by doing the on y axis we have the differential current ID that is i1 minus i2 and on x axis we have the restraining current that is i1 plus i2 by 2.

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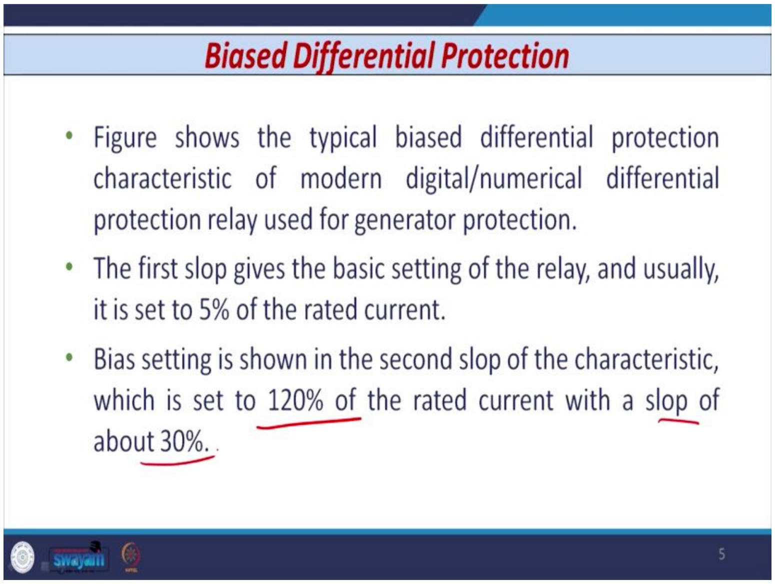

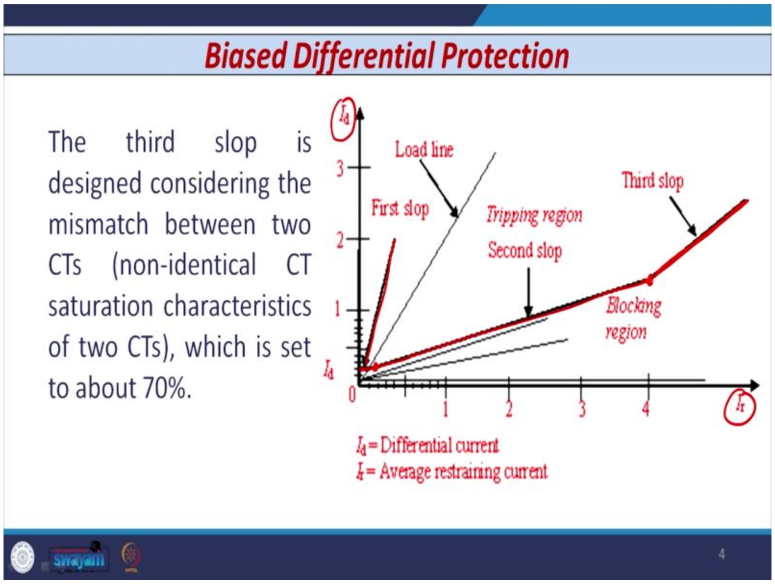

So, if I consider the first slope then the first slope gives or usually set at 5 percent or 10 percent of the rated current. So, you can see this is first slope, right which is only up to this, which is nothing but the 5 to 10 percent and that is nothing but the your differential current, that is i1 minus i2.

The second slope that is from here, from this point to this point, these two points you have the second slope and the second slope that is nothing but the set at 120 percent of the rated current with a slope that is about 30 percent.

So, the two points are there, what is the slope setting? That is 120 percent of the rated current and what is the value of slope? That is roughly around 30 percent, nowadays is in some digital differential generator relay the third slope that can also be given, so if third slope is given then its setting is roughly around 70 percent and its slope value that can be higher than this 30 percent roughly around the sum value. So, it depends on the requirement.

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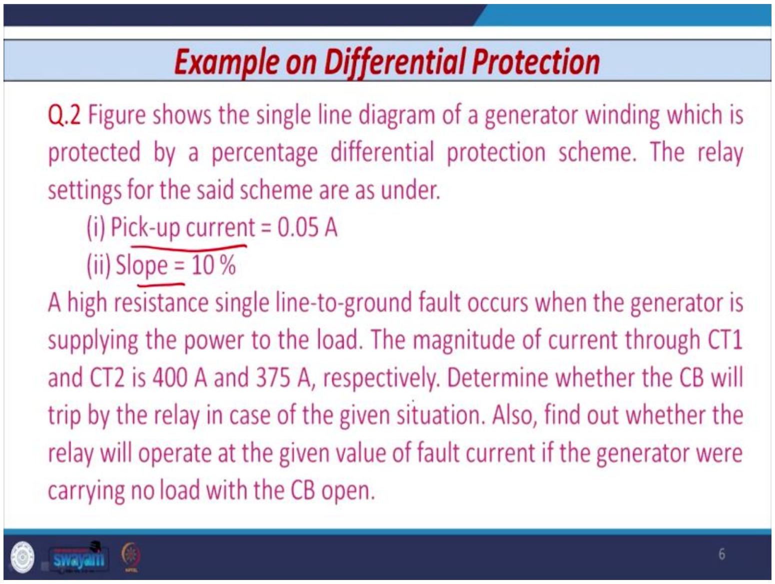

So, let us see solve one example that is based on the bias differential protection scheme.

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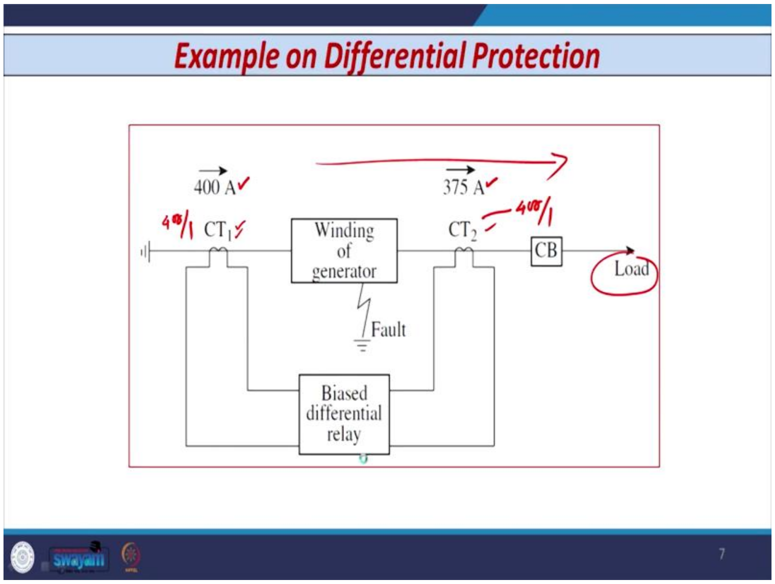

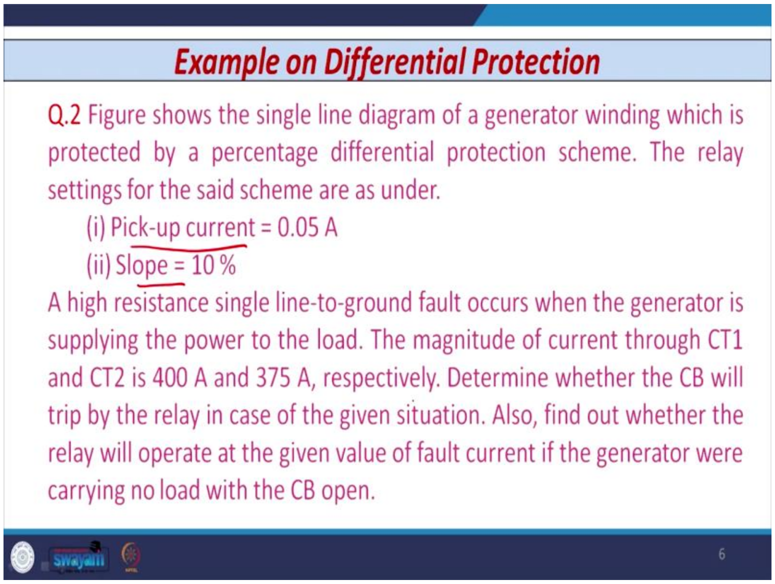

Let us assume that we need to protect the winding of the generator, the CTs are given that CT1 and CT2 and the ratio of this two CTs that is also given, let us say, 400 by 1 so, this CT ratio that is CT1, CT ratio that is 400 by 1 and CT2, CT ratio that is also 400 by 1. So, we need to protect this winding of the generator with the bias differential relay, the relay settings are given as under the pickup setting of the relay is 0.05 ampere.

So, its pick up value is 0.05 ampere and the bias setting or the slope setting that is 10 percent, if high resistance single line to ground fault occurs when the generator is supplying the power to the load. So, the load is also shown here and this generator is supplying power to the load at the time, the line to ground fault occurs.

And in this case if the magnitude of fault current through CT1 and CT2, that is 403 and 375 ampere. So, in this case the magnitude is 400 ampere, here it is 375 ampere, then you need to determine whether the relay will operate in this situation or not, two cases you need to consider, the first one the circuit breaker, that will be in closed condition. And the second one, the circuit breaker that is in open conditions. So, for both the cases you need to find out whether the relay will operate or not.

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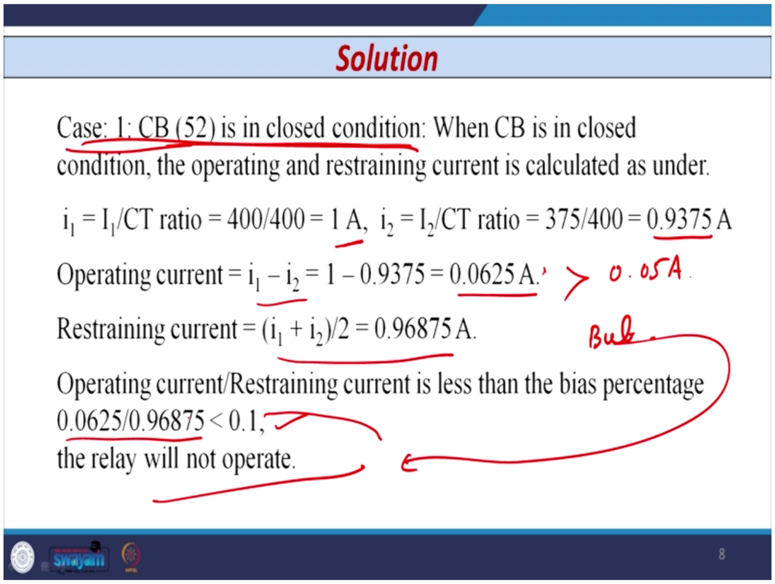

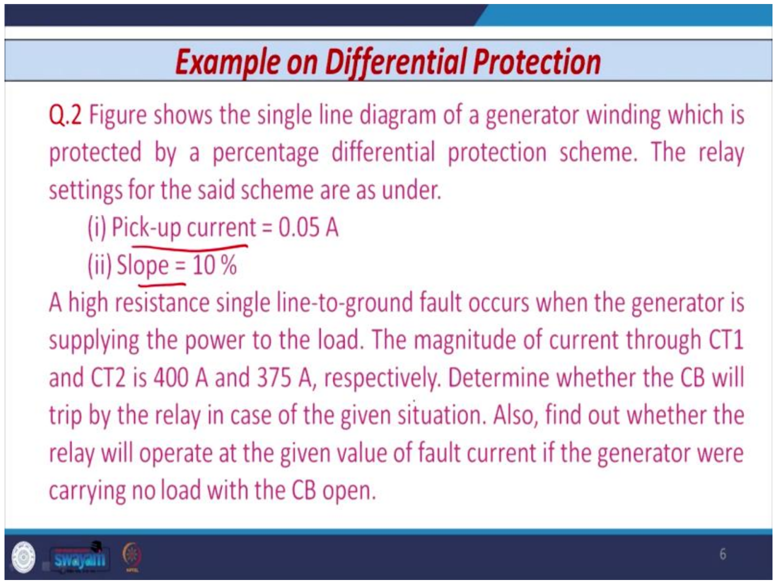

So, let us start with the first case, that is when the circuit breaker is in close condition. So, when the circuit breaker is in close condition, that is the first case, let us find out what is the operating current and restraining current in this case. So, we know that the capital I1 was given 400 and 375.

So, if I transferred this two current with this ratio of CT1 and CT2, then the current, small i1 that is 1 ampere and small i2 that is 375 by 400, so that comes out to be 0.9375 ampere, so the operating current that is i1 minus i2, that is 1 minus 0.9375 so that comes out to be 0.0625 ampere, the restraining current is i1 plus i2 by 2 so that comes out to be 0.96875 ampere.

Now, you can see that the operating current by restraining current, if I just take the ratio of the operating current that is i1 minus i2 and if I take in denominator i1 plus i2 by 2 this ratio, then that ratio, this value that comes out to be less than 0.1, why 0.1? Because the setting is given as 10 percent, slope setting that is 0.1.

So, if this value is 0.1, that means, the relay that is not going to operate, of course, we need to check the other condition also, that is i1 minus i2 that is greater than this value for the operation of relay where here value, this value is greater than the 0.05 ampere but you can see that the other setting that is the ratio of this two i1 minus i2 divided by i1 plus i2 by 2. That is not greater than 10 percent or 0.1, which is the bias or slope setting, hence relay is not going to operate.

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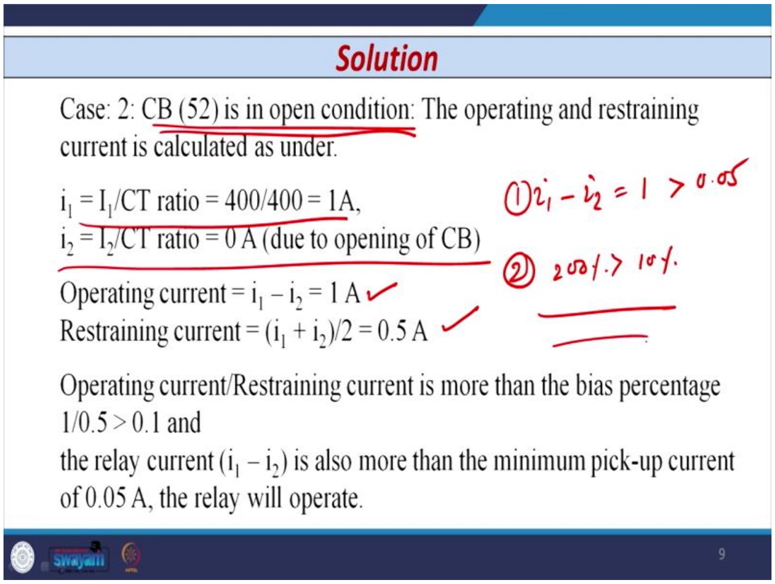

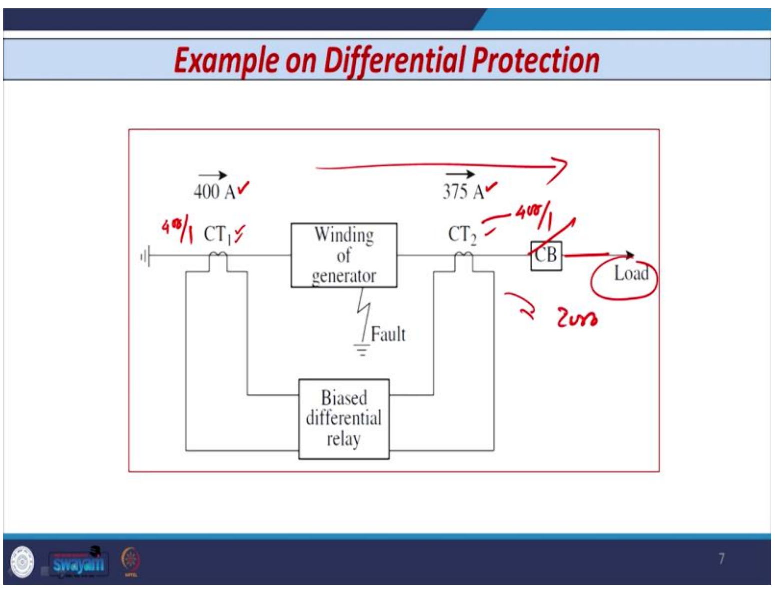

Let us consider the second the second case when the circuit breaker that is in open condition so when the circuit breaker you can see, this is in open condition then the current on this side that becomes 0. So, in this case, as the i2 current that becomes 0, because of opening of circuit breaker, the i1 current same as 400 or 1 ampere on secondary side. So, the operating current i1 minus i2 is 1 ampere and the restraining current is 0.5 ampere, 1 divided by 2.

So, the ratio if I consider i1 minus i2, the first setting is i1 minus i2 that is 1 ampere is greater than 0.05, that is satisfied. And the second that is the ratio of i1 minus i2 divided by i1 plus i2 by 2. So, 1 divided by 0.5. So that comes out to be 2 or 200 percent, that is greater than 10 percent. So, that means we can say that the relay operates at both the conditions are satisfied.

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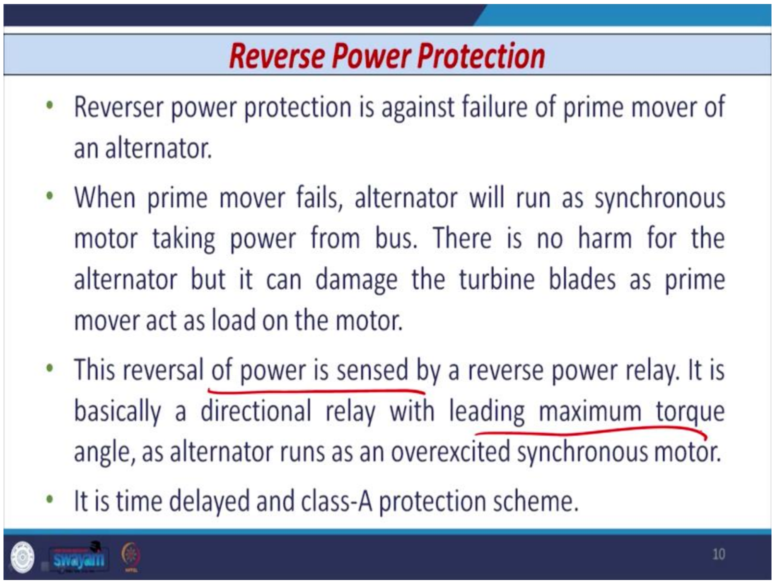

Now, let us take the another type of protection, which is very important as far as the large generator is concerned and that is known as the reverse power protection. So, reverse power protection is meant or used against the failure of prime mover of the alternator. So, we know that whenever with the generator prime mover is always connected. So, whenever the prime move fails the synchronous generator works or acts as a synchronous motor.

So, there is no harm if synchronous generator acts or works as a synchronous motor. But whenever the synchronous generator acts as a synchronous motor then it takes power from the bus instead of feeding power to the bus and the prime mover that will act as the load. So, whenever prime mover acts as a load that is going to damage the prime mover, we can say turbine.

So, we need to detect the reversal of power in this situation. So, the reversal of power that is sensed by reverse power relay. It is basically a low forward power relay so it is a power relay so it has to two coils current coil as well as the voltage coil. So, it is basically a directional relay with the leading maximum torque angle, why leading maximum torque angle? Because when the synchronous generator acts as a synchronous motor, it acts as over excited synchronous generator and this type of protection is a time delayed protection and class A protection, we will see why this is a time delay later on.

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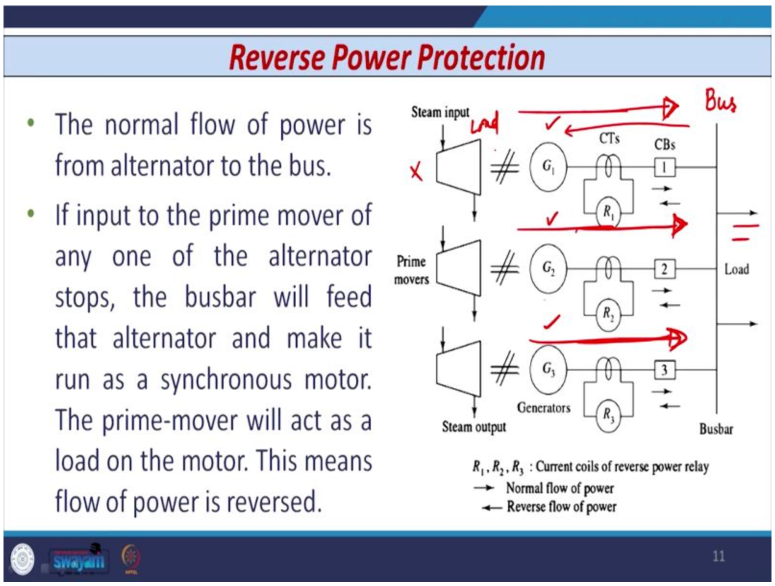

Now, to understand the reverse power protection, let us consider this diagram. So, here I have shown a group of generators, G1, G2, G3 these generators are connected to the bus. So, the generator is feeding power to the bus, like this, in this direction. Now, whenever and of course, the load that is also connected, the transmission lines or group of transmission lines so in normal condition the flow of direction of power is like this.

Now whenever, if the input to any of the prime mover, that stops then in that case, the synchronous generator that acts as a synchronous motor. Let us say, this will fail so now, this synchronous generator acts as a synchronous motor so it takes power from the bus where this steam, turbine acts as a load. So, whenever such situation happens, then this needs to be detected otherwise it will damage the turbine or the prime mover.

Now, we know that in actual fields depending upon the type of power plant we use either thermal, hydro, gas or diesel a different types of turbines that is used or prime mover that is used. So, let us see if such situation exist when the synchronous generator acts as a synchronous motor and it takes power from the bus instead of feeding power to the bus. Then, depending upon different types of turbine, let us consider or let us discuss what happens or what is the damage to each turbine.

So, let us start with the first turbine, let us say it is a steam turbine. So, the power plant is a thermal power plant or coal based power plant and whenever the synchronous generator acts as a motor, then this steam turbine acts as a load or as a pump so steam that is going to be trapped on the blades of the turbine.

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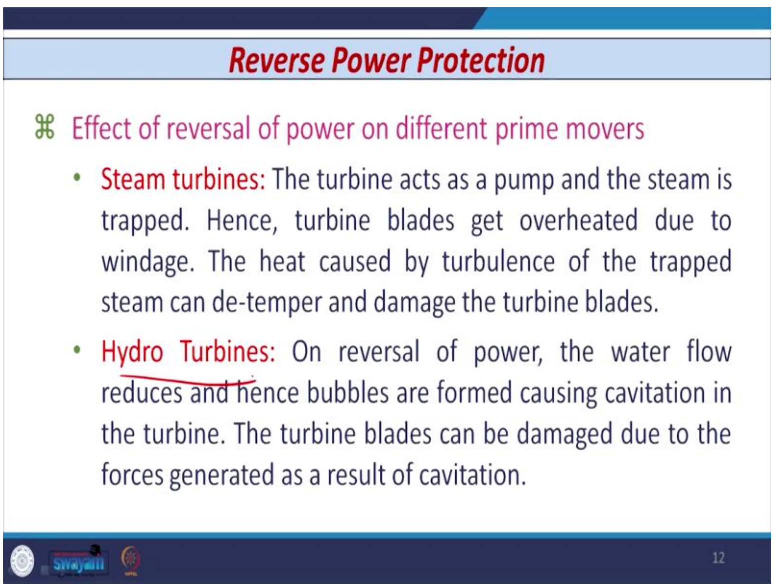

So, the turbine blades get overheated and because of the heat caused by turbulence of the trapped steam. It can also damage or de-temper the turbine blades. So, we need to detect the situation and we need to remove the turbine, as well as the generator. The next that is known as the hydro turbines. So, if we use hydro power plants then on the reversal of power, the water flow reduces and hence, that is going to form the bubble which in turn cause the cavitation in the turbine. So, the turbine blade because of this cavitation excessive force that is put on the turbine blades and that can also damage because of the cavitation.

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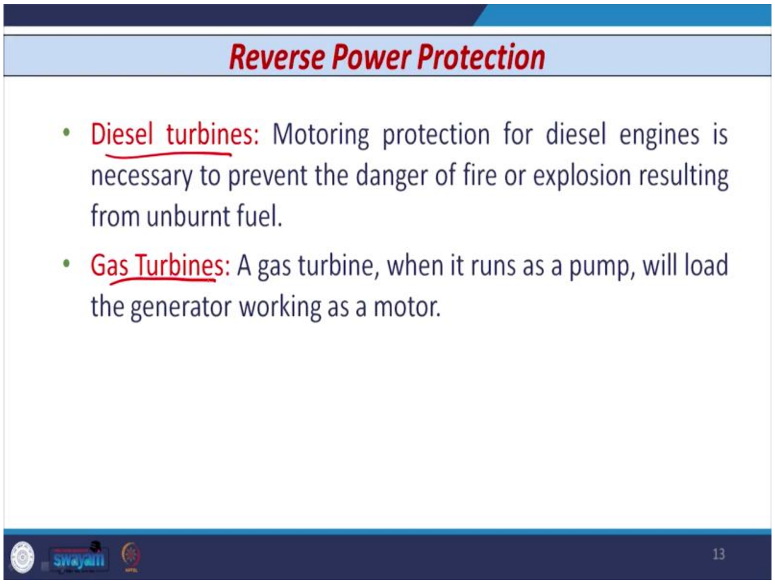

The next type of turbine that is known as diesel turbines, so if you have a diesel generator, then the whatever turbine we use motoring acts for diesel engine that is necessary to prevent the danger of fire or explosion, because in this case the fuel that is not burned, it is an unburned fuel. So, it may danger or some explosion may occur so we need to detect it and remove it.

The next type of turbine that is known as the gas turbine. So, the gas turbine when it acts as a load then the load of the generator that will act as a motor so we need to detect the situation and remove the gas turbine otherwise again there is a problem of fire in the gas turbine.

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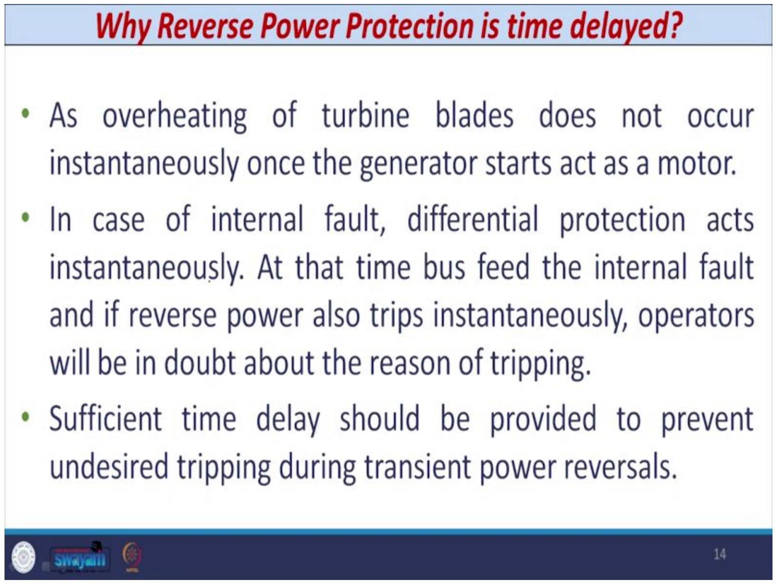

So, before we discuss the actual scheme used in the reverse power protection, let us discuss why reverse power protection is a time delayed protection. So, we know that the overheating of turbine blades that is not going to occur immediately or instantaneously. Once the generator that acts as a motor, the second problem is whenever there is an internal fault in the generator in case of differential protection.

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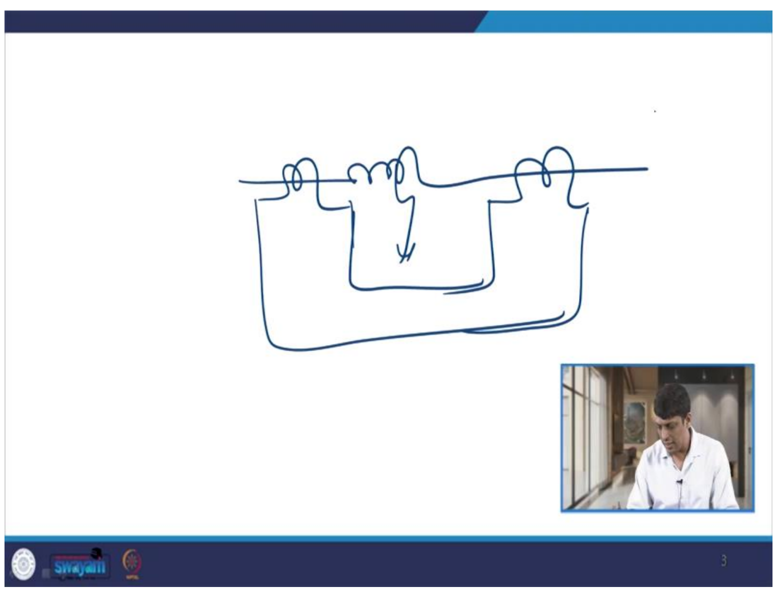

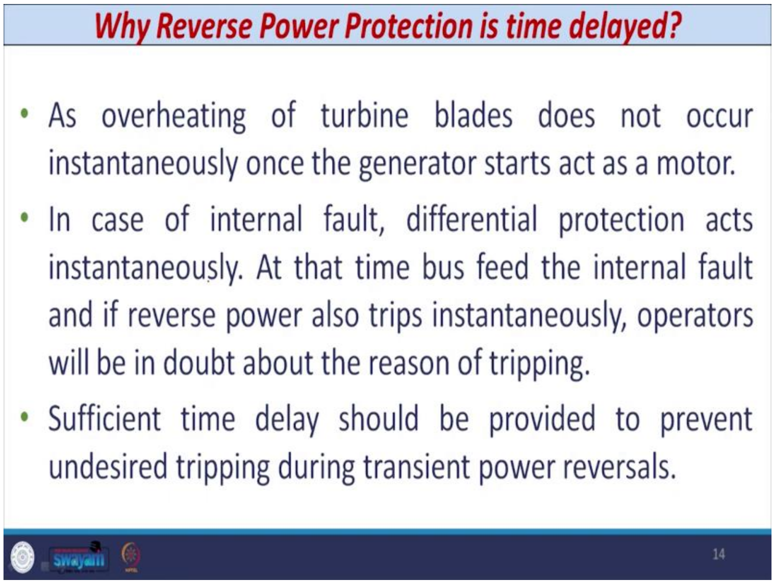

So, we have discussed earlier, that whenever if I use the differential protection here and whenever there is an internal fault inside the generator then the power is fed, like this. So, in this case, as the power is fed by the bus in case to the internal fault whenever it occurs in the winding of the generator.

Then if reverse power if we keep the reverse power as an instantaneous operation and operators may in confusion that whether the generator has tripped because of the internal fault in the winding of the generator, or because of the reverse power. So, to avoid this, reverse power protection is always a time delayed protection. So, sufficient time delay should be provided so that such type of mal operations should not occur, particularly in case of transient power reversal.

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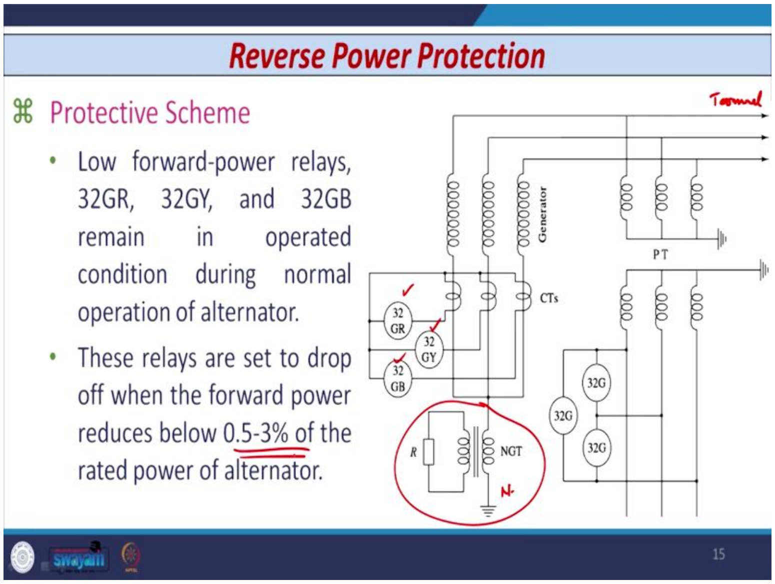

Now, let us discuss what type of scheme, protective scheme we use. So here you can see, I have shown the three phase generator. So, this is the neutral of the generator, so neutral side and this is the terminal of the generator here and you can see that as I told you it is a power relay, directional relay.

So, it has two coils, voltage coil and current coil so, current input that is given through CT so three relay that is connected here. That is 32 is the number given to reverse power relay so in R phase, Y phase and B phase and the three, again three voltage coil that is also connected and input is also given so 32 G, R, B and Y in each phase that is also connected.

So, in normal condition, there is no reversal of power, power is normal so, in this relay, 32 relay or reverse power relay remains in energize condition, operating condition. So, whenever there is a reversal of power, then this relay drops up because of this and this value, you can consider as the 0.5 to 3 percent of the rated power. So, if this power reduces below this then the reverse power relay or low forward power relay comes in picture.

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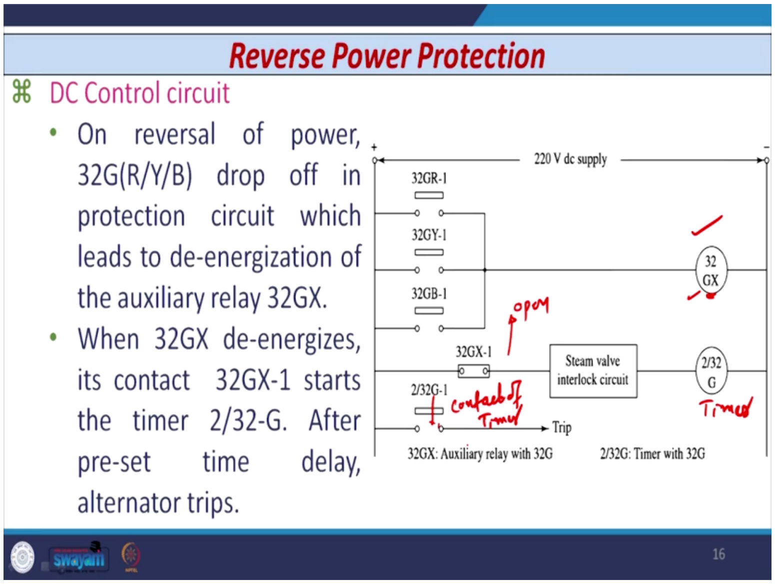

So, if I draw the control circuit, as I told you, in normal condition, the power is in normal or normal operation. That means the generator is feeding power to the bus so this relay remains in energize condition so, when it is in energize condition then this coil of 32GX , GX it is auxiliary relay connected with the reverse power relay, this is also energized so its contact normally, close contact this remains in open condition.

So, no tripping is given or no command is given to the 2 by 32G this is a timer coil and this timer has some contacts, this is the contact of timer. So, in normal condition as it is remains in energized conditions because power is normal so, it remains in energized condition and this contact. 32GX 1 that remain in open condition.

Now, whenever there is a reversal of power 32G relay drops off so because of this there is a de-energization of the coil of this 32GX so, this will remain, this contact 32GX 1 remain in close condition, because I told you earlier in earlier chapter also that in control circuit all the circuit breakers are shown in open condition and all the relay coil are shown in de-energized condition so I have show this is in de-energize condition.

So, this will remain in close condition so it gives command to the timer, after when the time of this timer elapses then his contact closes and it gives a tripping command so that operator has to take certain action assuming treating that some reversal of power that takes place and because of that the reverse power relay 32 operates.

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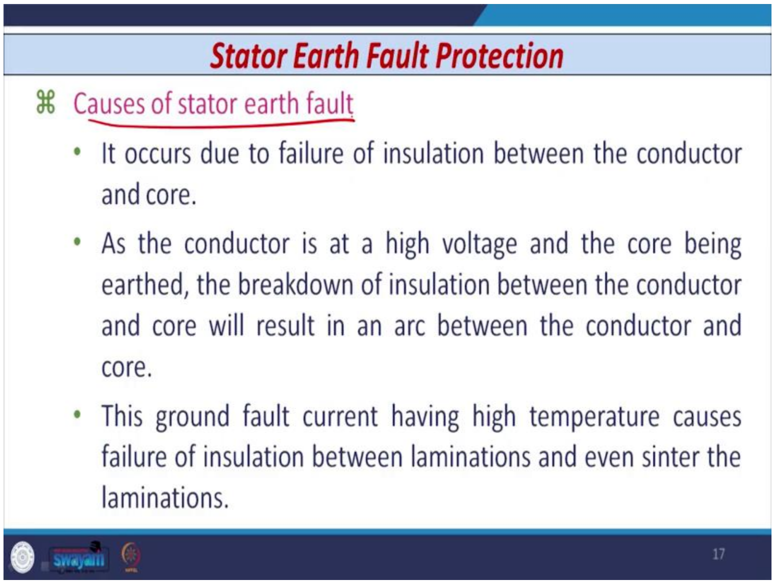

Now, the next type of scheme that is known as Stator Earth fault protection scheme so, let us first discuss what are the causes of stator earth fault. Now, this type of problem occurs because of the failure of insulation between the conductor and core so we know that the conductor in the stator that is at high voltage, high potential whereas the core that is being earth so any breakdown of insulation between the conductor which is at high potential and the core which that is at being earth that will result in an arc between the conductor and the core.

Temperature of this arc, whether it is very high or low or medium that depends on the current flows through this arc so the ground fault current that flows through these arc, if its magnitude is very high then the temperature of this arc that is also very high. Then, in this case is damages the lamination and sometimes if the temperature of the arc is very high that it can also (())(19:30) the laminations.

This will if the laminations are affected then there is a direct increase of the Eddy current losses and that will also damage the large portion of the stator core, repair of such damage that will take a very long time, maybe of the order of 1 month or even higher so, there is a loss of the revenue.

If and if this is all this thing is possible when such type earth fault occurs near the neutral of the generator. If earth fault occurs near the terminal of the generator, then this type of destruction would be very high and sometimes it could be repairable. So, that means whenever such type of stator fault occurs in the generator then we need to restrict the magnitude of stator earth fault current to the very low so that the destruction of because of this because of increase in the temperature of the arc should be minimum.

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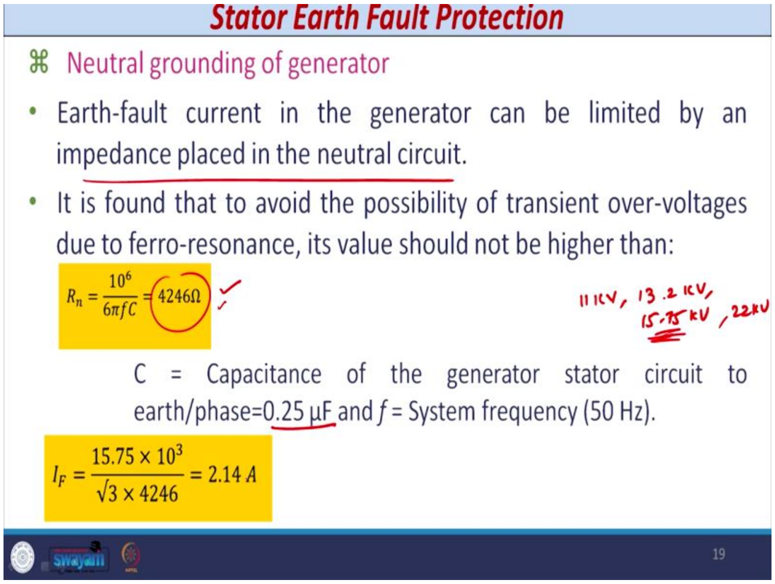

So, the earth fault current, in the case of generator that should be limited by some ways. So, the best, easiest way is to connect the impedance or the resistor in the neutrals circuit of the generator. Now, it is found that if we wish to connect impedance or resistor in the neutral circuit of the generator then what is its value, we need to keep.

So, its value should be such that the transient over voltages due to ferro-resonance effect should not be higher than this value or that mean so if I connect the resistor in the neutral of the generator then its value should be this only, it should be higher than this otherwise, the ferro-resonance effect may be very predominant and there are fair chance of transient over voltages so the value of resistor connected in the neutral circuit of the generator that should be restricted by the equation 10 raise to 6 divided by 6 pi fC, where f is the system frequency, let us assume it is 50 hertz, the C, that is the capacitance of the generator stator circuit to the earth per phase value.

So, if I consider this value, let us say the 0.25 micro Faraday maybe for the 15.75 kV generator like 15.75 kV is the line to line voltage of the generator. There are different ratings of the generator like 11 kV, 13.2 kV or the 15.75 kV sometimes 22 kV is also available, so if I consider middle value 15.75 then the value of Rn by putting f 50 hertz, C 0.25 micro fera hertz the value of Rn comes out to be 4246 ohm.

If I put this value that means if I connect this value of resistor in the neutral circuit of the generator then the magnitude of fault current that comes out to be for 15.75 kV generator, it comes out to be 15.75 kV divided by 3 divided by root 3 so phase voltage and whole divided by this value that is 4246 ohm so that magnitude of fault current in case earth fault that comes out to be 2.14 ampere so if we restrict this then we can say that whatever is the destructive effect that is not very high.

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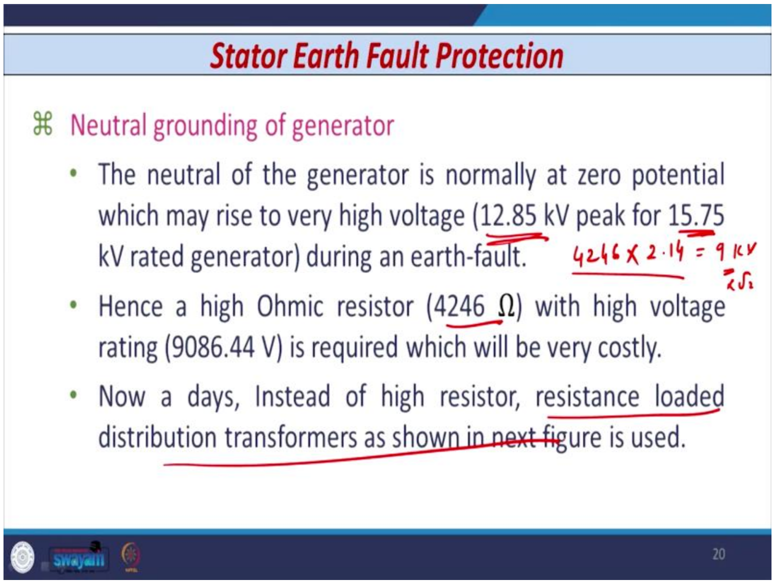

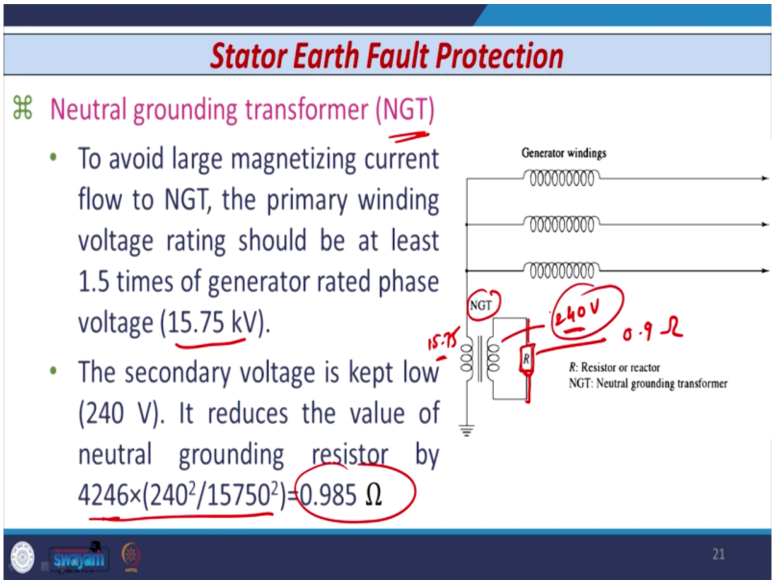

Now, if I use, if I connect this value of a resistor roughly around 4000 ohm or kilo ohm in the neutral of the generator, then the potential of the neutral of the generator that increases, why? Because we know that we need to connect very high value of resistor, roughly around 4000 ohm, 4 kilo ohm and its voltage rating that should be also very high because if I connect this value 4246 ohm then the potential of the neutral, that becomes 4246 into what is the fault current if I connect this? It is roughly around 2.14 ampere, we have already calculated.

So, if you multiply this, this should be around roughly 9 kV. If I again consider the peak value then the peak value should be roughly around 12.85 kV that mean if I multiply this with root 2 and this comes out to be roughly around 12 kV. So, for 15.75 kV generator if I connect a resistor in the neutral circuit of the generator with this value then its voltage rating should be minimum line voltage of the generator.

So, this is very costly, so nowadays instead of connecting directly such a high value of resistor in the neutral circuit of the generator people uses the distribution transformer and this type of transformer that is known as the neutral grounding transformer NGT. So, if I connect the value of NGT then its voltage rating, its primary value rating should be line voltage of the generator.

So, let us say it is 15.75 kV and the secondary of this NGT, so this is 15.75 kV primary and the secondary that should be say 240 or 230 volts. And here we need to connect the resistor so if I calculate the value of resistor, then the resistor comes out to be 4246 ohm, we have already calculated, multiply by the N2 square by N1 square where N2 is 240 volts and N1 is the 15.75 kV.

So, if I add this, the value of R that comes out to be only 0.9 ohm roughly and its voltage rating should be always 240 volts that is why we always use the neutral grounding transformer and on the secondary of this we connect the resistor so that magnitude of fault current in case of stator earth fault that should be restricted.

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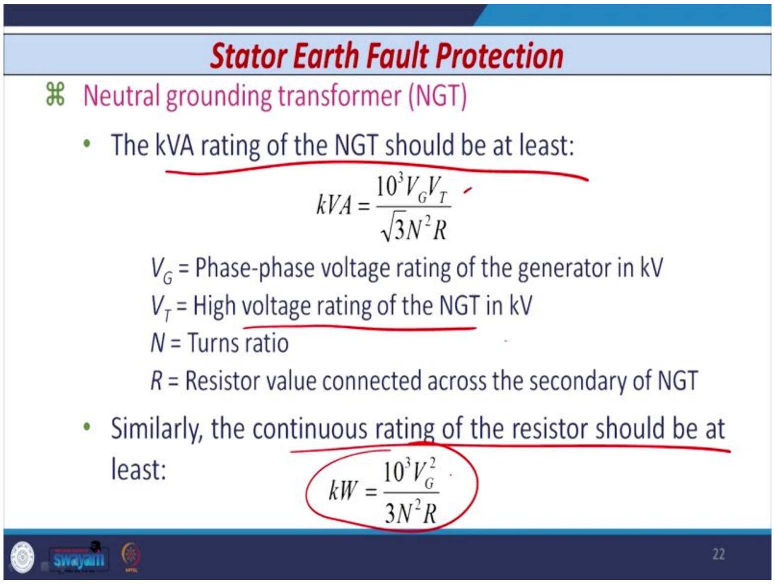

Now, if I considers the neutral grounding transformer than the kVA rating of the NGT, that should be minimum or equal to 10 raise to 3 VG VT divided by root 3 into N square R where VG is the phase to phase voltage of the generator, usually it is taken in kV, VT that is the high voltage rating of the NGT that is also in kV, N is the turns ratio and R is the resistor connected across the secondary of neutral grounding transformer.

Similarly, whatever resistor you connect and then secondary of NGT its continuous rating should be again given by this equation where VG that is again the high voltage of the NGT, N is the turns ratio and R is the resistor connected.

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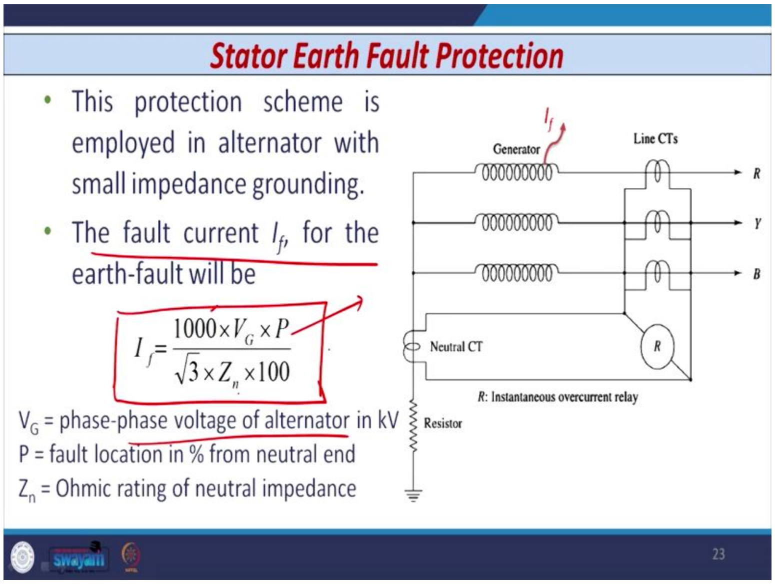

So, let us discuss what type of protection scheme that is used in case of stator earth fault. So, you have the generator here and you can connect the resistor here through NGT and if I connect here the protection scheme that employed for stator earth fault then the magnitude fault current that is given by the equation that is the, this equation. So, you have the 1000 multiplied by VG multiplied by P, where VG that is the phase to phase voltage of the alternator, so if I have 11 kV alternator VG should be 11 kV, if I have 15.75 kV alternator, then VG should be 15.75 kV and it is taken in kV itself.

The Zn is the ohmic resistor connected and the P that is the percentage or fault location in percentage or the percentage of winding to be protected from the neutral side. So, how much percentage of winding should be protected, if I use this equation?

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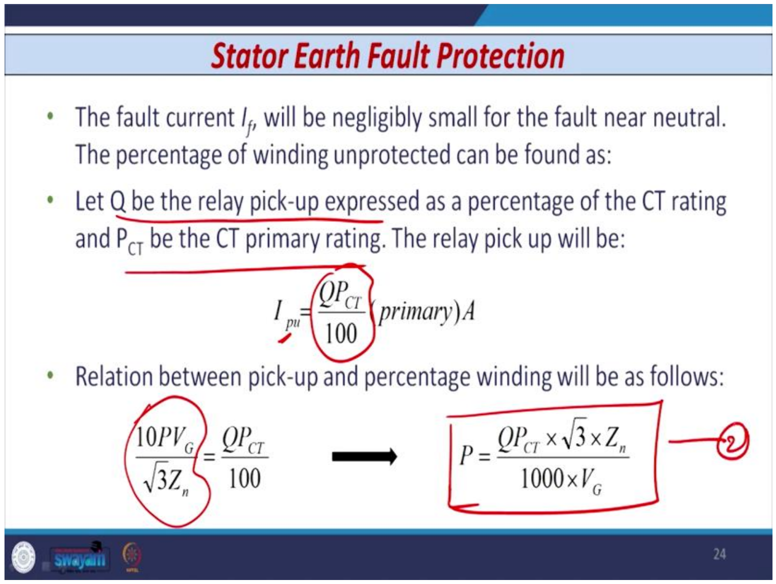

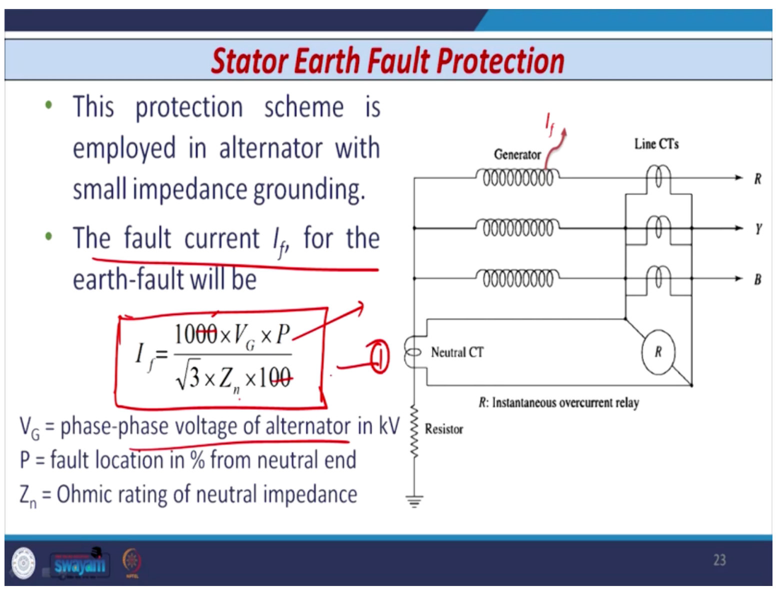

So, with this, if I consider the fault current, that should be negligibly small for a fault near the neutral then the percentage of winding unprotected that can be easily find out so, there are different cases, the fault can occur at from the neutral of the generator to the terminal of the generator.

So, if fault occurs at neutral of the generator then the percentage of finding that remains unprotected or protected, that can be easily find out. So, for that we need to consider the rating of the CT as well as the pickup value of the relay. So, if I consider Q that is the pickup expressed in terms of percentage of CT rating and P CT, that is the CT primary rating, then the pickup value of the relay that should be given by Q into P CT by 100.

So, this Q that is nothing but the pickup in terms of percentage of CT secondary P CT is the primary rating of the CT. So, I pu is the pickup value of the relay and this I pu that should be equal to what? The magnitude of fault current, we have considered here. So, this value if I solved this, then this should be nothing but the 10 VG P divided by root 3 Zn.

So, the value of this 10 VG P divided by root 3 into Zn that should be equal to the pickup value of the relay, so that is Q P CT by 100. So, the percentage of winding that remain unprotected from the neutral of the generator that is given by the equation Q P CT root 3 Zn divided by 1000 VG so, this equation is very important, as well as this equation is also very important.

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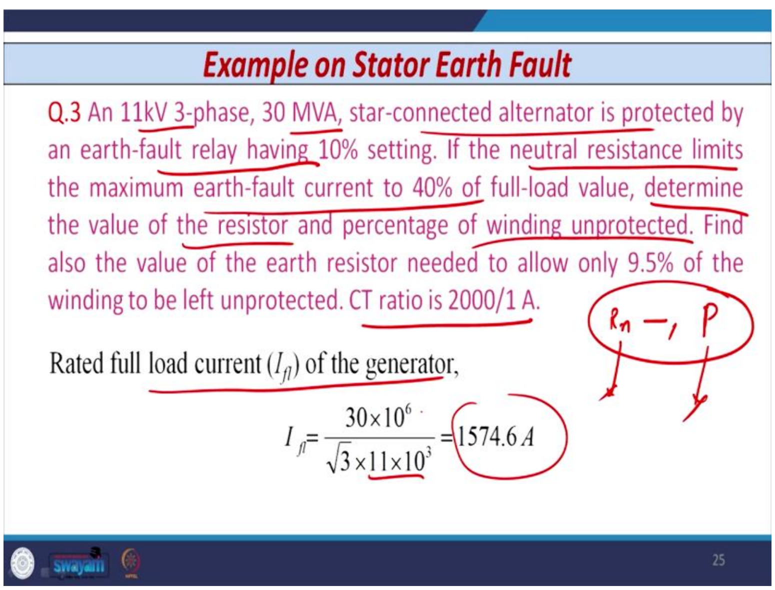

So, now with this, to using these two equations, let us solve one example. So, if I consider the 11 kV 3-phase 30 MVA star connected alternator, which is protected by an earth fault relay having 10 percent setting. If the neutral resistance limits the maximum earth fault current to be 40 percent of its full load current of the generator then we need to determine what is the value of resistor we need to connect and what is the percentage of winding that remains unprotected? So, we need to calculate the Rn, as well as we need to calculate the capital P. What is the resistor you need to connect and what is the value of P or the percentage of winding that remain unprotected from the neutral side, it is always from the neutral side.

We have to also find out the value of earth resistor needed, second case to allow only 9.5 percent of the winding that remain unprotected and you need to also consider the CT ratio, that is already given 2000 by 1 ampere. So, let us solve this example, let us first find out full load current of the generator, so it is 30 MVA or 30 into 10 raise to 6 divided by root 3 into 11 kV, so we can easily find out, 1574.6 ampere.

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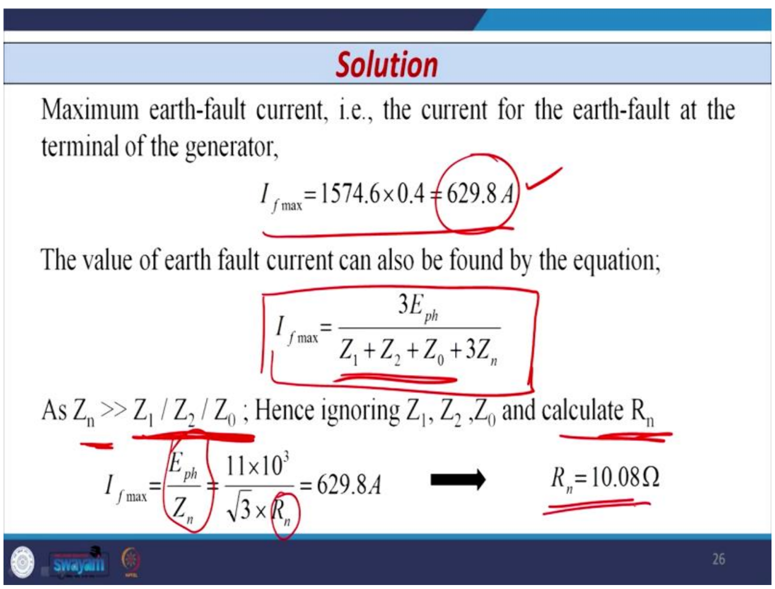

Now, what is the maximum earth fault current? It is 40 percent of this value, so the maximum earth fault current that is the 40 percent of the 1574.6 ampere so that comes out to be 629.8 ampere. You can also calculate the value of earth fault current using this equation, this is well known equation in case of fault analysis with a maximum of earth fault current that is 3 times phase voltage divided by Z1 plus Z2 plus Z0 plus 3Zn where Z1, Z2, Z0 are the positive, negative and zero the sequence impedance and Zn is the impedance connected in the neutral circuit of the generator.

This Zn that is very, very greater than these 3 values, Z1, Z2, Z0 so you can neglect it. And you can also consider Zn that as Rn neglecting the inductance so the value of I f maximum that is nothing but 3 E ph divided by 3Rn. So, you have E ph by Zn or E ph by Rn. So, E ph that is already given rating of the generator that is 11 kV, so 11 kV divided by root 3 that is the phase voltage divided by Rn, so that comes out to be, what? This value 629.8 ampere we already calculated. So, if I put this value here, that is, then you can easily calculate the resistor that is to be connected that is 10.08 ohm.

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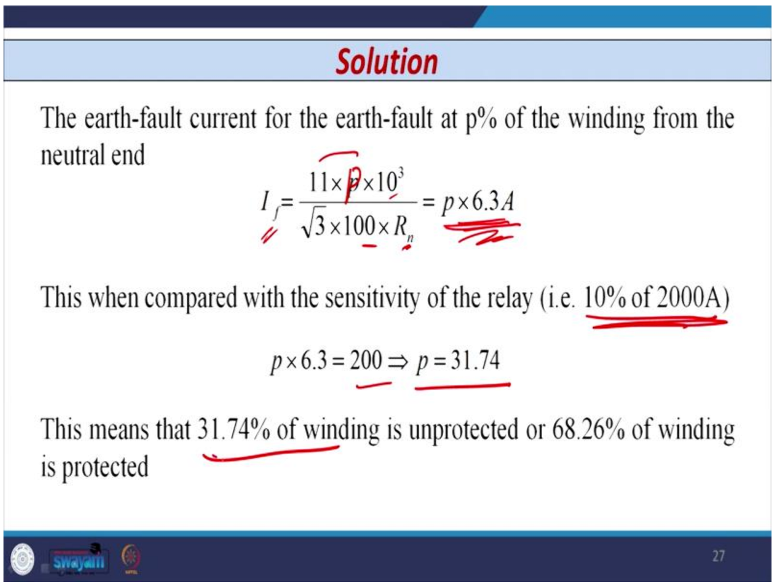

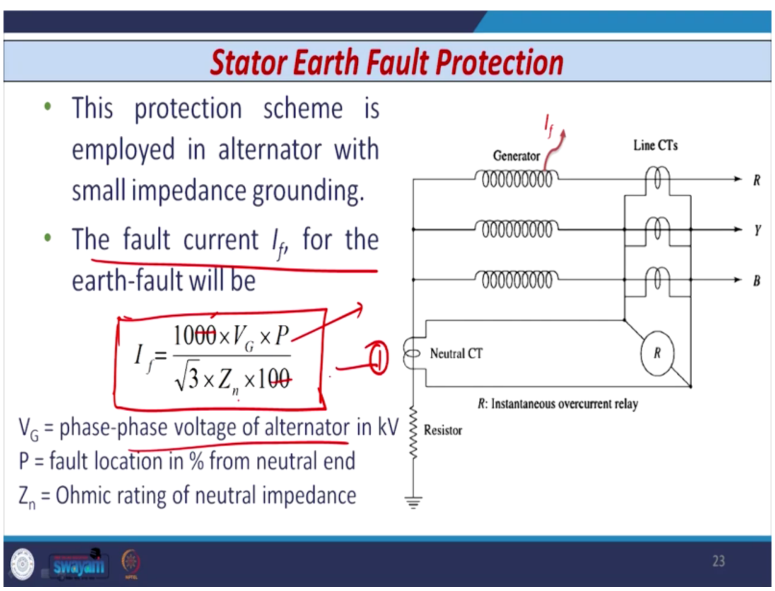

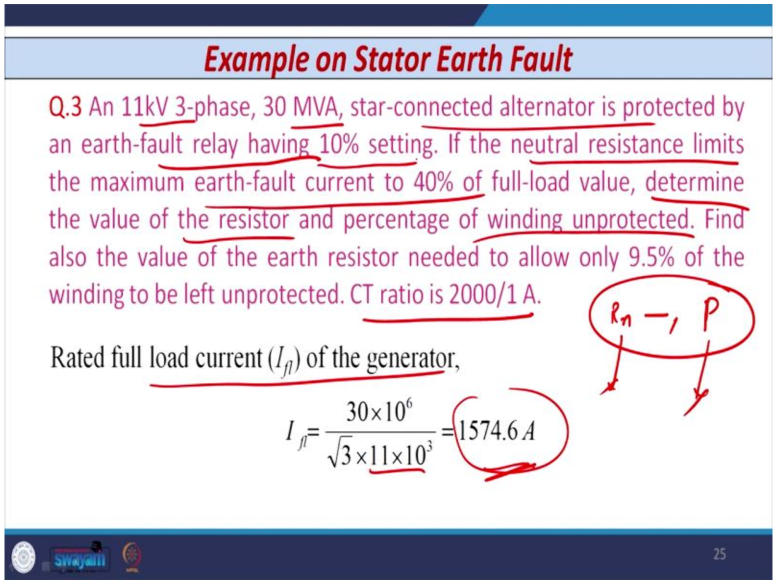

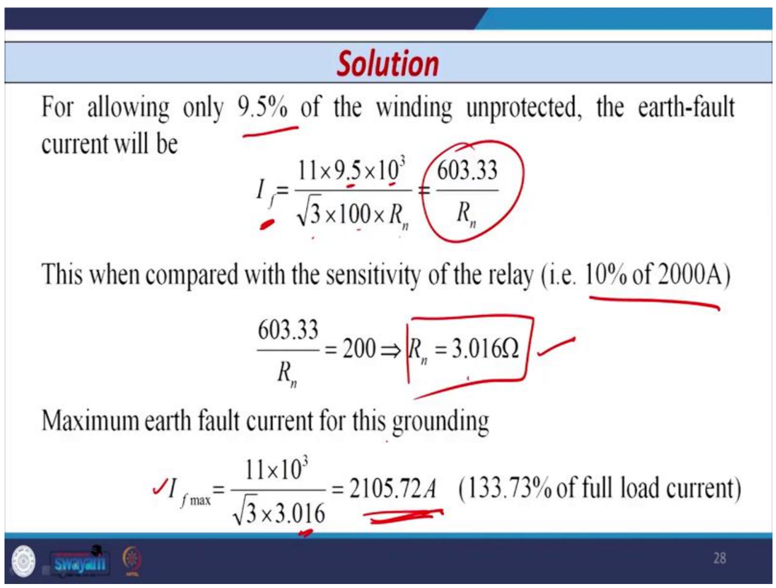

So, if I use this resistor and if I use the equation of the fault current, that is which equation? This equation that is 10 VG P divided by root 3 Zn or 1000 VG P. Then you can 1000 VG that is the line to line voltage of the generator 11 P that is the percentage of winding to be remain unprotected from the neutral root 3 Rn in to 1000.

So, you can easily find out this value that is p into 6.3, because p is not given Rn you can put this value 10.08 so you can find out I f in terms of p times some value. Now, when you compare this with the sensitivity or the pickup which is already given 10 percent, right it is already mentioned that the pickup is this 10 percent setting. So, 10 percent of the CT primary which is 2000 by 1 ampere or 10 percent of 2000.

So, if I compare p into 6.3 equal to this value, 10 percent of 2000 that is 200 then p comes out to be 31.7. So, that means that 31.74 percent of the winding that remain unprotected from the neutral side or 68.26 percent of the windings that is protected from the terminal side and now here, the winding to be remain unprotected is 31.74 or unprotected winding that is reduced to 9.5 percent from this 31 percent, then what value of resistor you need to connect?

So, again if I put the value of I f that 11 VG that is p that is 9.5, 10 raise to 3, root 3 100 Rn. So, this value comes out to be this if I compare this value with the sensitivity 10 percent of 2000 that is 200 then Rn comes out to be 3.016 ohm. So, in earlier case you can see the value of Rn is 10 ohm so the value of fault current is limited, lower. Here, the value of Rn comes out to be 3.016 ohm.

And if I use, put this value, then you can see that the magnitude of fault current increases, so as I wish to increase the percentage of winding that remain unprotected from 31 percent to 9 percent then again, the value of resistor, which I connect, its value reduces and hence the magnitude of fault current increases.

So, always I need to be optimized between whether I wish, want higher value of fault current so that higher value of fault current is there, then the percentage of winding remain unprotected that is less. However, whether we want on the other side, the lower value of fault current in which the percentage of winding that remain unprotected from the neutral side that is higher. So again, we need to optimize.

So, in this class, we started our discussion with the bias differential relay, we also calculated one example, and then start a discussion about the reverse power protection and finally the stator earth fault protection of the generator and we have also calculated one example. Thank you.