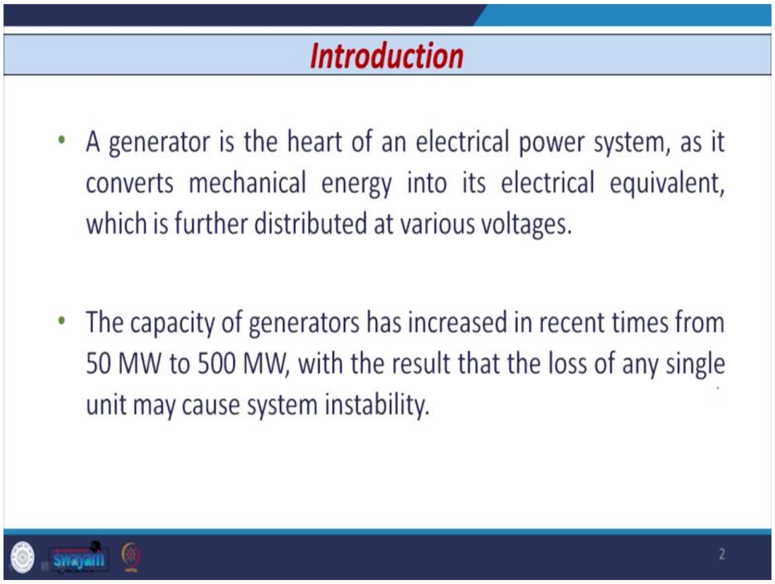
Power System Protection and Switchgear
Professor. Bhaveshkumar Bhalja
Department of Electrical Engineering
Indian Institute of Technology, Roorkee
Lecture No. 28
Protection of Generators – 1

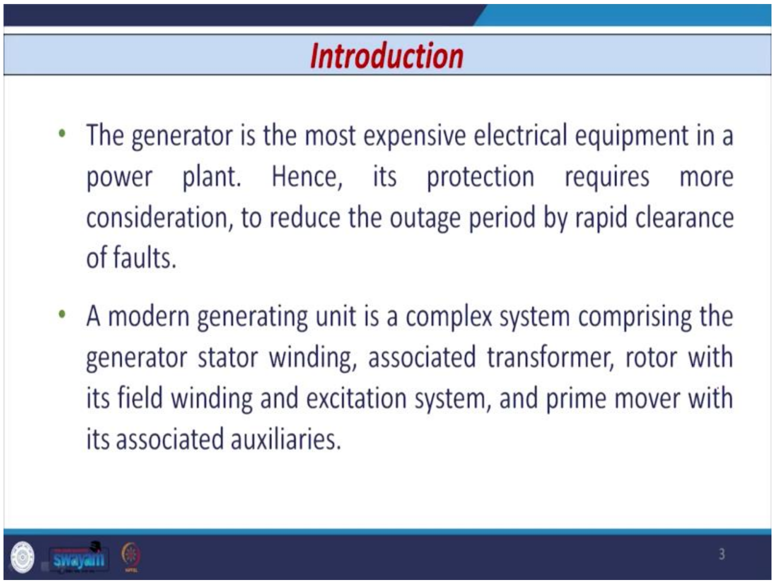
So, let us discuss the next chapter that is known as the Protection of Generators. So, we know that the generator is the heart of electrical power system because it converts mechanical energy into electrical equivalent and this power that is further distributed initially transmitted and then finally distributed to the consumers. Consumers can be residential consumers, commercial consumers or industrial consumers.

(Refer Slide Time: 00:57)



Now, the capacity of generator has increased roughly say a few megawatts to the 500 or 1000 megawatt. So, if any of the single unit that is going to be lost than that can lead to the instability of the power system network. So, to avoid this we need particular separate protection for generators.

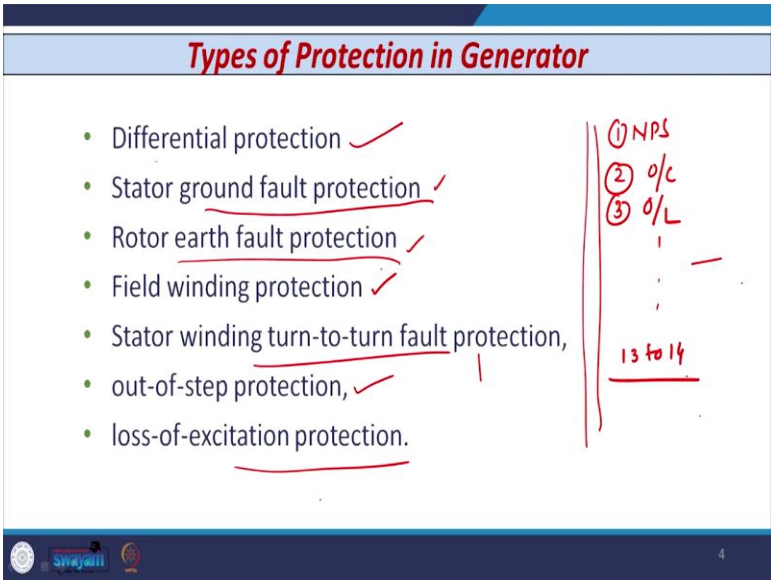
(Refer Slide Time: 01:18)



Now, it is a very expensive device and particularly it is used in the power plant, so its protection requires more concentration because our objective is to protect the generator so that we can minimize the outage time by rapid clearance or rapid detection of fault, I am talking about the electrical fault or internal faults in the generator. So, the modern generator unit is a very complex unit, why it is complex?

Because it comprises stator winding, associated transformer, rotor winding along with the excitation system, so that is field winding and the prime mover along with associated accessories. So, whenever we consider the protection of generator, we need to consider all this equipment along with the generator also, because if failure of any of the equipment that is going to affect the generator itself.

(Refer Slide Time: 02:10)



So, looking to this different equipment used in the generator or associated equipment with the generator, we are talking about large generator, then different types of protections are used. This protections are starting from the first that is the differential protection, so it is meant for the instantaneous operation in case of short circuit or fault inside the winding of the generator. The next is the stator ground fault protection, so if there is an insulation failure between the conductor and the core of the generator basically the earth fault type, then such type of protection is required.

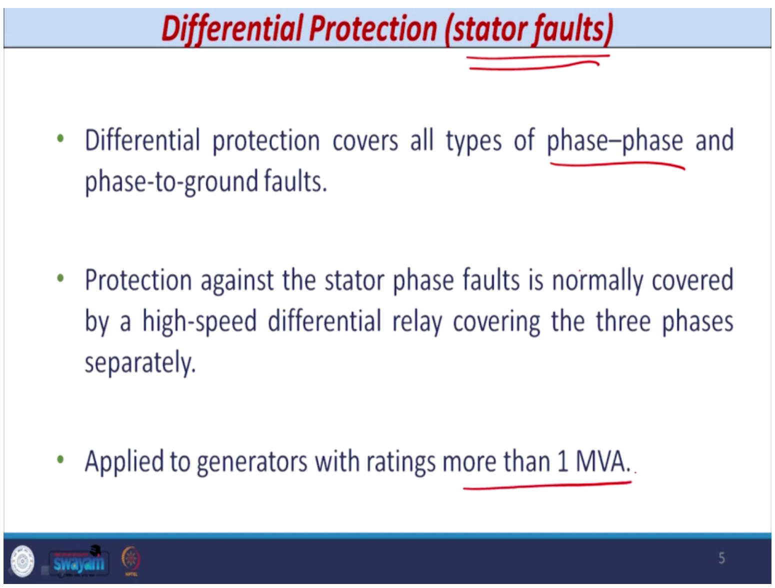
Then the rotor earth fault protection, so if there is a earth fault in the rotor first earth fault there is no problem, but whenever there is a second earth fault, then the circulating current flows and that is also going to damage, so rotor earth fault protection is also required. The next one is the field winding protection, if there is a failure of field then also the generator is affected and hence there is a need to protect against such type of phenomena.

The next one that is the turn-to-turn fault protection as in case of transformer the turn to turn fault, if there is a few turns shorted in any of the phase or multiple phases then the differential protection is not able to detect this thing, because it operates on the Kirchhoff's current law, so where the current entering and current leaving that is to be compared. So, if there is a shorting of few turns in a particular phase, then let us say 4 turns, 5 turns, 10 turns, then the current entering and current leaving that remains same.

So, differential protection is not capable to detect such type of fault and we need separate protective device which is capable to detect turn to turn fault, if it occurs in the winding of the generator. The next that is the out-of-step protection, so this type of protection is also required and the loss of excitation protection this is also require. Now, I have listed only few protections along with this there are certain other types of protection like negative phase sequence protection.

So, if there is a negative sequence current flows in the generator, then then generator should be protected. I have not also listed the overcurrent protection, overload protection and few many mores others also, but I have listed only few few of them, so when we deal with the generator protection there are around 13 to 14 types of total protections required in case of large generator.

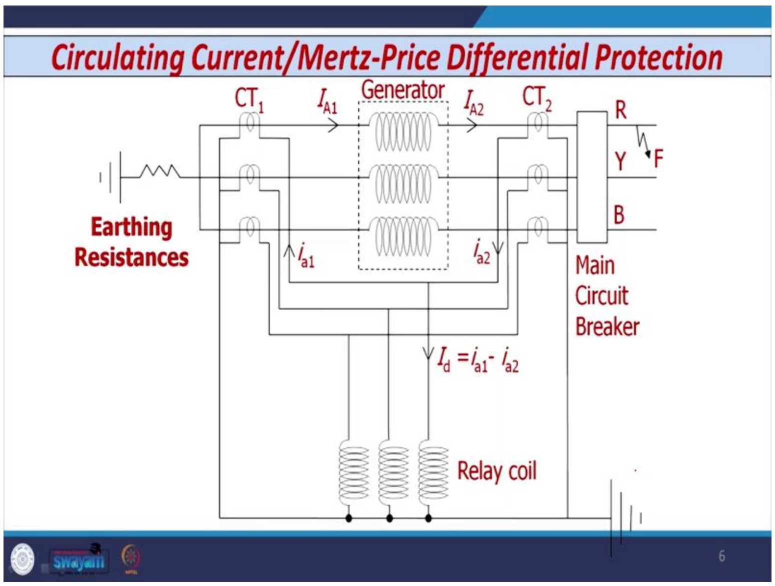
(Refer Slide Time: 04:52)

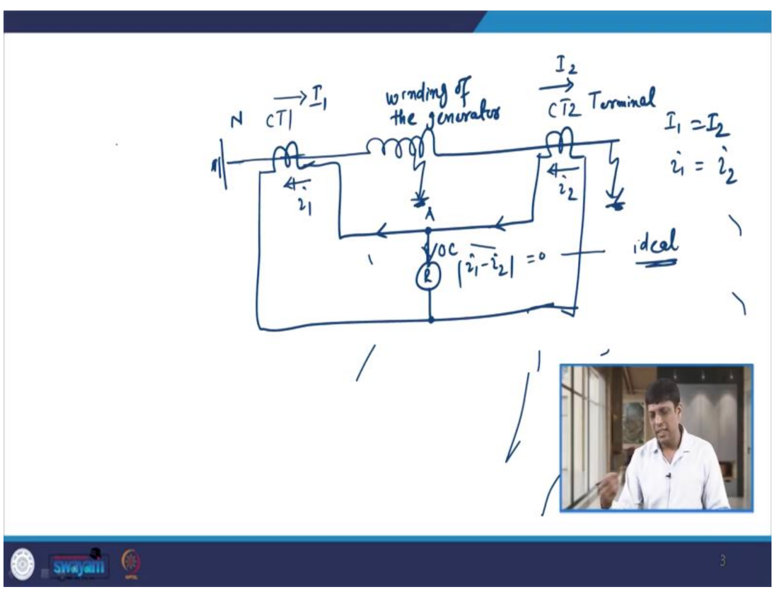


Now, let us start with the first type of protection scheme used in the large generator that is the differential protection. So, differential protection is normally meant for the stator faults, so any face-to-face fault between the two windings, then such type of fault should be detected and this type of fault should be cleared instantaneously rapidly, so the detection time in this case that is roughly around one cycle or even lower than that, so that the outage or the damage to the generator that should be minimized.

The next is the protection against phase fault that is normally covered by high speed differential relays, wherever any earth fault is there, then that that should be covered by separate earth fault protection, this is particularly in case of large generator. And differential type of protection as we have discussed in case of transformer also, that when we apply differential protection in case of transformer, then it should be applied to the power transformer, higher rated transformer. Similarly, in case of generator also differential protection when we apply it should be applied for the generators having rating more than 1 MVA.

(Refer Slide Time: 06:03)





So, let us start with the first type of scheme that is used in the differential protection and that is known as circulating current differential protection scheme. So, to understand this we have already discussed in case of transformer that if we wish to protect let us say the winding of the generator, so this is the winding of the generator, large generator, then what we have to do is we have to put I am just drawing the single line diagram, so it is applicable just one phase.

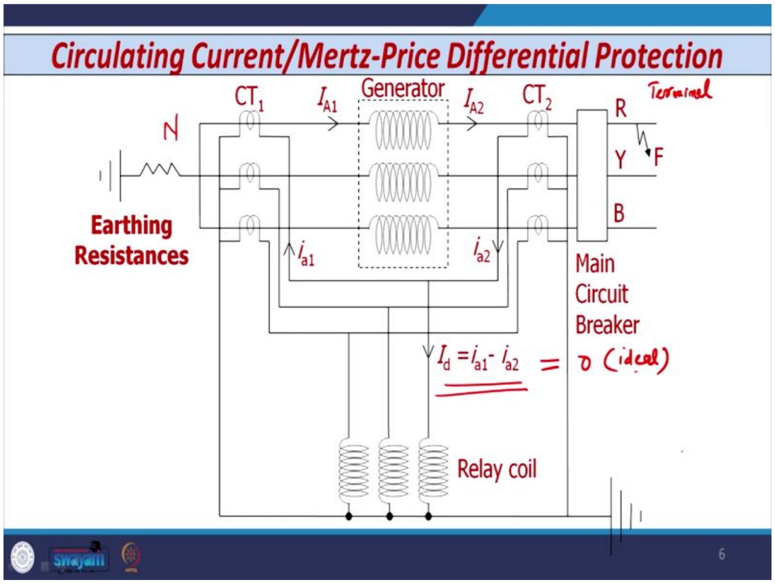
So, here on this side the neutral of the generator is there and on this side you have the terminal of the generator is there, so on neutral side as well as on terminal side, we put one CT and this CT that is connected like this same as we connected in case of differential protection of transformer and we put the relay that is here, so this is the relay and this relay has one coil I have not drawn but it is nothing but the operating coil of the relay.

So, if the current through this CT, let us say CT 1 and CT 2 that is say primary current is capital I1 and capital I2, then this scheme circulating current differential protection scheme operates on the principle that current entering and current leaving should be same. So, I1 that should be equal to capital I2. So, if I just draw the secondary current, so here the small i1 which is 180 degree out of phase and hence similarly the small i2, then these two currents i1 that should be equal to i2 also, during ideal condition.

So, this current will flow and the current that flows through the operating coil of the relay that is the i1 minus i2, let us say absolute value. So, whenever this i1 minus i2 differential current that is in normal condition when there is no fault inside the winding of the generator, then this current should be 0, this is your ideal condition, but in actual field, this current should not be 0 because of so many reasons, we are going to discuss it.

But the main objective of circulating current differential protection is that if any fault, internal fault occurs inside the winding, then these two currents i1 and i2 small i1 and small i2 are there is a significant difference in these two current. So, the i1 minus i2, if it exceeds some pickup value our plug setting or threshold the relay then the relay should operate. Whereas in case of external fault somewhere here or somewhere here on any other side if any other device is connected, then the relay should not operate.

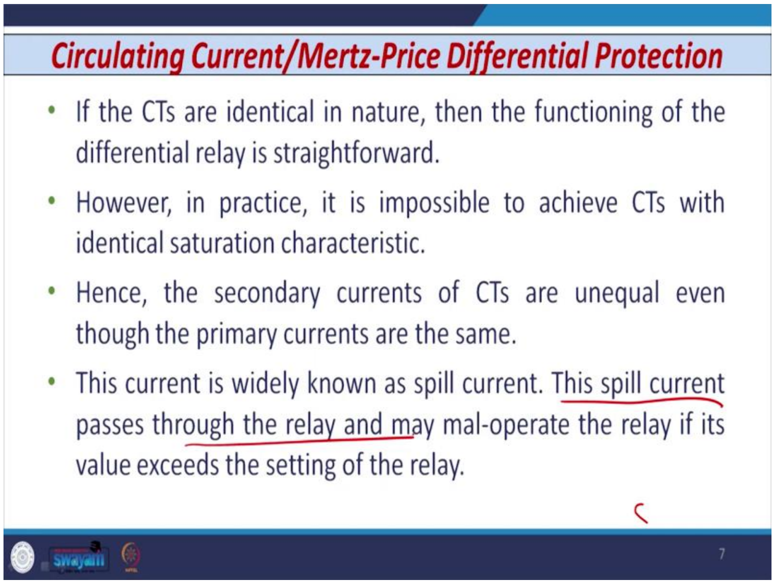
(Refer Slide Time: 08:58)

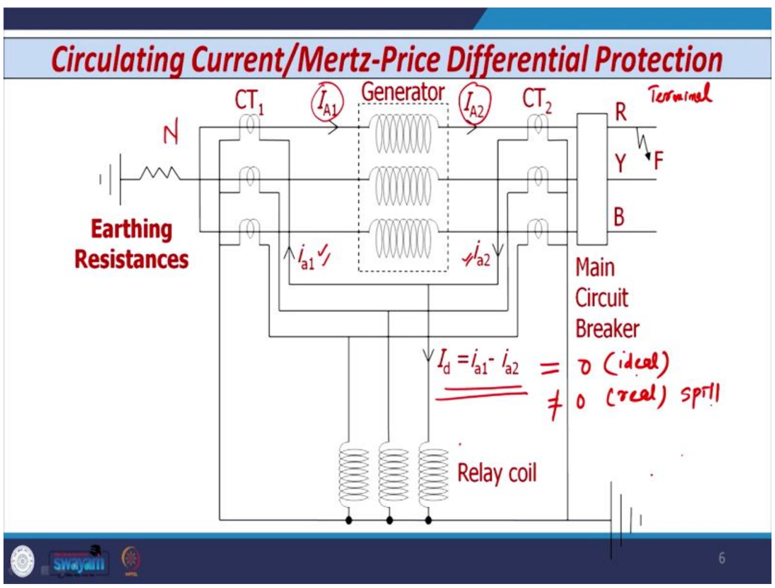


So, if we consider the same scheme, as we have discussed in three phase, then you can see that here you have this is the neutral of the generator and then you have a 3 set of CTs are there, let us say CT1 and on this side that is the terminal of the generator where you have the another set of CT, let us say CT2. And this CT1 and CT2 that is connected same as we have discussed and the operating coil of the relay that is there through which the differential current that is the difference of two currents, let us say ia1 and ia2, that flows and if that exceeds the pickup value, then the relay operates.

Now, as we have discussed that this differential current that flows through the operating coil of the differential relay in case of circulating current differential protection they should be ideally 0, I should say ideal is 0, but practically it is not 0, why it is not 0? Because of two reasons.

(Refer Slide Time: 10:02)



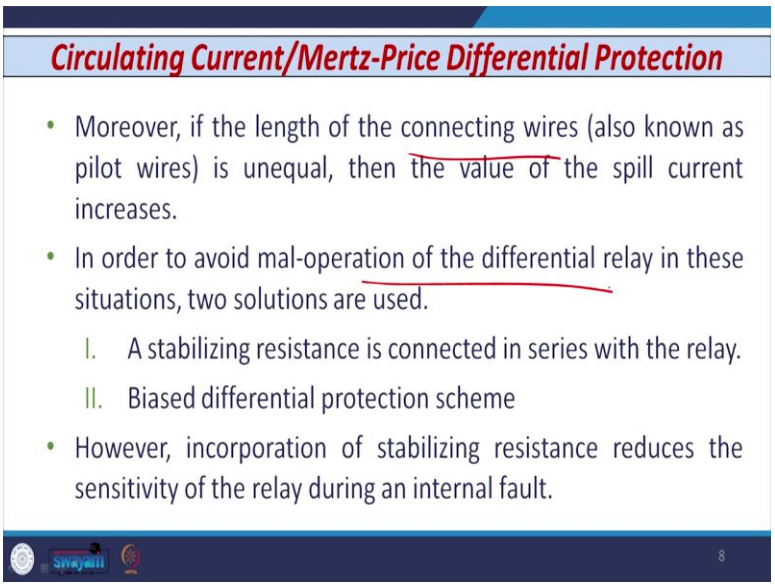


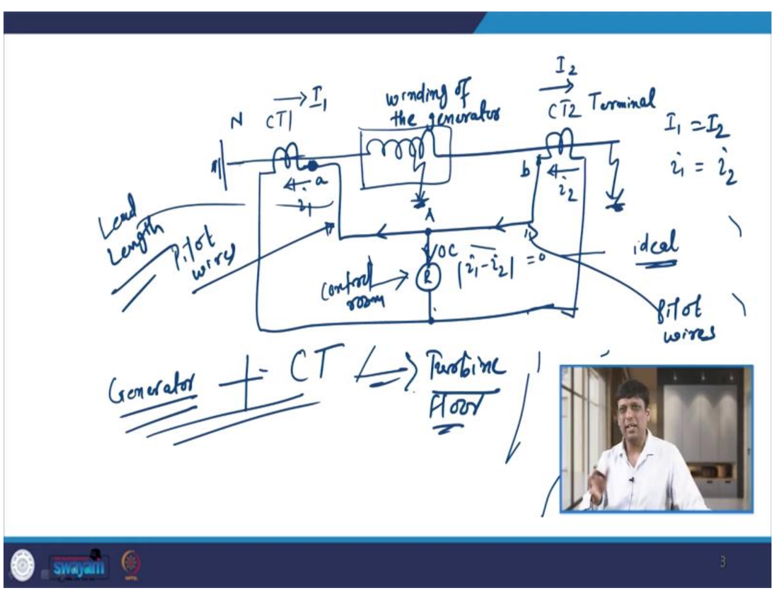
The first reason that is the characteristic of this two CTs are not identical, even though if it is purchased by same manufacturer then also the CT saturation characteristic of this CT1 and CT2 both are slightly different, so the even though the primary current this capital IA1 and capital IA2 2 are same, then also this small ia1 and small ia2 this are not save.

So, some difference of this two small ia1 and ia2 that will always flow through the operating coil of circulating current differential relay, so this current is not 0. So, this current is not 0 in actual condition, because of the non-identical CT saturation characteristic and the current which is not 0 that flows through the operating coil of relay in when there is no fault in normal condition, then this current that is known as the spill current. So, spill current that always flows through the relay.

So, spill current that is always passed through the relay and we have to do carry out the setting of the relay particularly in this case in such a way that whenever the spill current flows through the operating coil the flux setting should be greater than this value, so that relay does not operate in this situation.

(Refer Slide Time: 11:24)





The second point because of which the spill current increases, that is the unequal lead lengths, so if I consider again the same figure then let us say that we have discussed that this winding to be protected of the generator, so let us say the generator that is there at the turbine floor near the prime mover, the CT that is also located there near the generator, so this is also plus CT, both are located near the turbine floor. Whereas, if I consider the relay then the relay that is located in the control room.

So, obviously from the this point let us say the point small a to the capital A we have to run the wires through which the CT secondary current flows, this wires are known as the pilot wires. Similarly, from this point let us say small b to the capital A, the pilot wires are definitely there, so if I consider the length of the pilot wires from small a to capital A and from small b to capital A this should be equal. If these two are equal then the voltage drop should be equal and hence the current that is the spill current that is not there both are balance.

However, practically it is not possible that the lead length, this is known as the length or the lead length, so lead length in actual or practical field should not be equal. So, lead length, it is always unequal and the other reason is we can either there is no guarantee that we can always fix or connect the relay in the control room at the equipotential point, there is no guarantee because of some reasons. So, due to this reasons unequal lead length, the there is always an increase in the spill current that flows through the operating coil of the relay.

So, that means because of these two reasons, the first that is the unequal lead lengths and second that is the non identical CT saturation characteristic the some current that is known as field current that always flows through the operating coil of the circulating current differential relay. So, if we use such type of scheme that is circulating current differential protection scheme, then this relay way may operate in normal condition or in case of external fault.

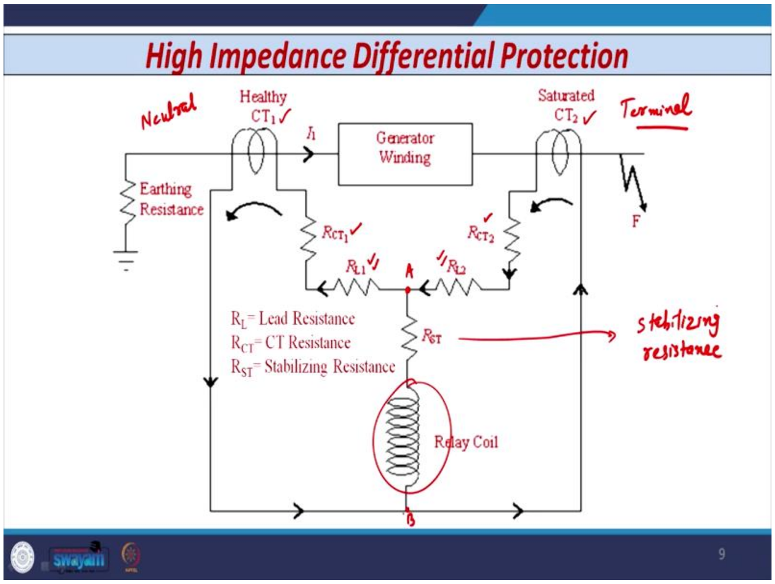
So, what is the remedy of this circulating current differential protection scheme because we have discussed that there are two main disadvantages of circulating current differential protection scheme. So, the remedy is, there are two remedies two solutions are available, the first either we use the stabilizing resistance or we connect the some resistance in series with the relay coil, so that the differential current that should be reduced and the second remedy is we should go for the next level of scheme that is known as biased differential protection scheme.

However, each scheme has certain advantages and disadvantages, so let us starts discussion with the stabilizing resistance first solution that is going to be connected in series with the relay coil.

However, the main disadvantage of this scheme if we connect any resistor in series with the relay coil to reduce the differential relay or differential current for this field current, so that it should not operate in case of external fault because of non-identical CT saturation characteristic and unequal lead length, then the sensitivity of the relay that should be reduced in case of internal fault.

However, let us discuss this scheme. So, this type of scheme where we connect the resistor or the stabilizing resistance in series with the relay coil that is known as high impedance differential protection scheme.

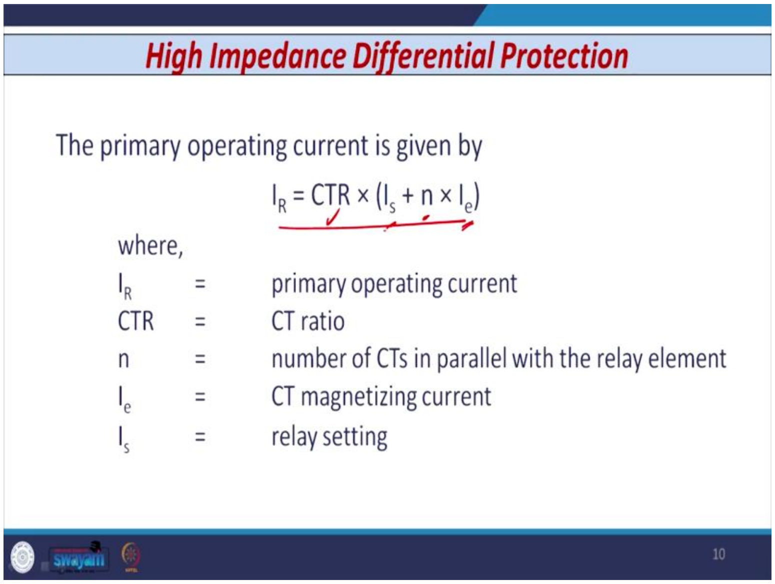
(Refer Slide Time: 15:34)



So, whatever resistor we connect in series with the relay coil that is known as stabilizing resistance, stabilizing resistance. So, let us discuss this scheme, so you can see that again I have considered the CT1 and CT2 here on each side on the neutral side, this is the neutral side of the generator which is normally grounded through some resistor or reactor and this is the terminal side of the generator. So, you can see that the two CTs are there and the secondary of this CT that is the current that will flow and the difference of this current that will flow through the relay coil.

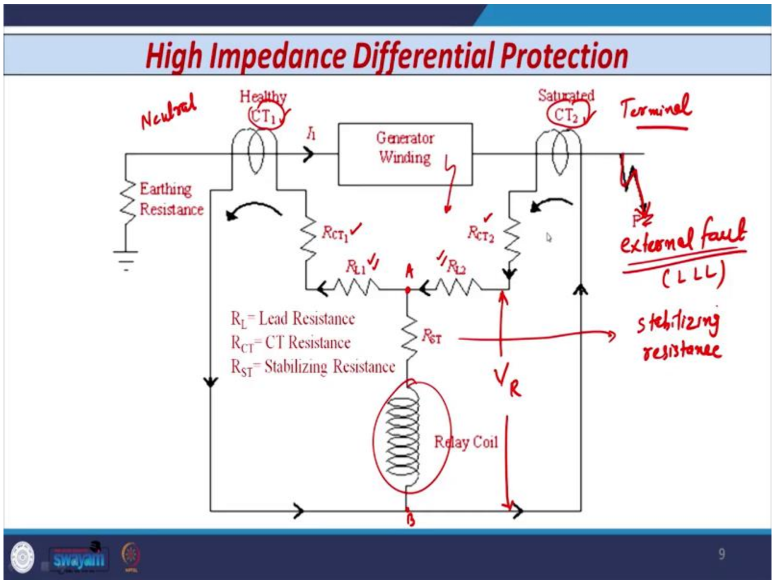
Now, you can say I have also shown the RCT1, that is the resistance of CT secondary on CT1 and I have also shown the resistance of the CT secondary 2 on terminal side, along with this I have also shown the lead resistance RL1 on the CT secondary 1 to the relay and I have also shown the lead resistance to that is RL2 from the CT secondary 2 to the point where relay is connected. So, let us say this is the point A and this is the point B where the relay is connected.

(Refer Slide Time: 16:53)



Now, if I consider the primary operating current then that is given by the equation given as, so the IR is the primary operating current CTR is the CT ratio Is is the secondary current and n is the number of CTs connected in parallel with the relay element and the Ie that is the magnetizing current of the CT, where Is is the relay setting.

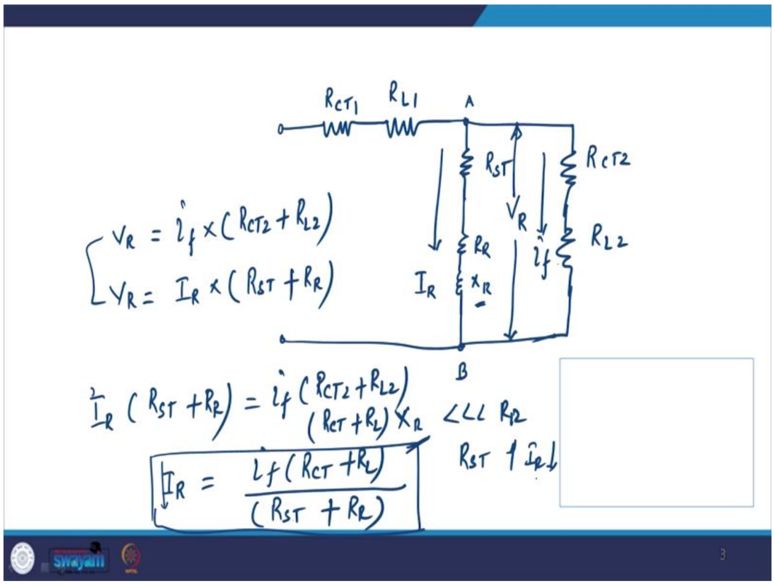
(Refer Slide Time: 17:21)

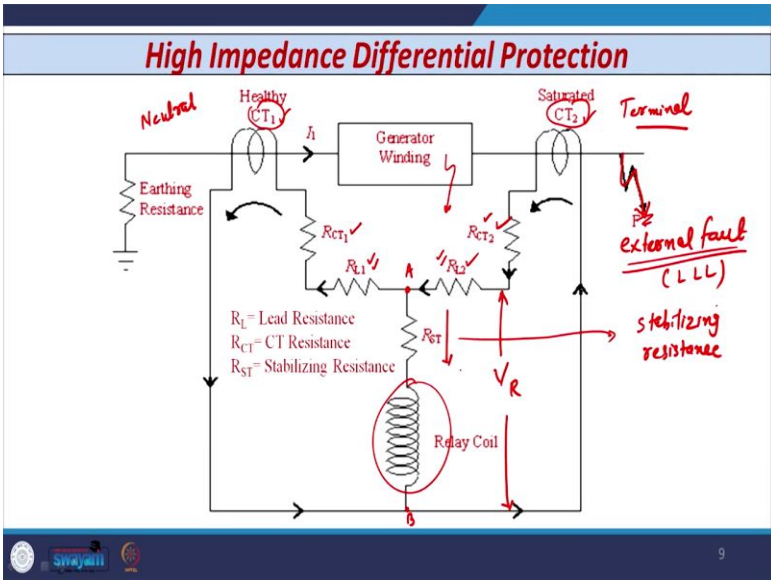


So, if I consider in this figure, what is the voltage across this? Let us, say the voltage across this that is VR, across the relay, where between point A and B. So, suppose if I consider that the let us say there is an external fault somewhere here, this is an external fault now keep in mind this fault is the out of June fault for this differential relay, because any fault occurs in the winding of the generator then and then this scheme should operate.

So, in case of external fault, let us say the severe most fault triple L fault, what will happen this this CT, which is near to this external fault, let us say CT to get saturated, whereas the CT1 which is near the neutral of the generator, that is healthy, it is working in the linear range, where this CT2 is saturated, so it enters the saturation region. So, because of this if this CT1 and CT2 has some inductance, then the equivalent circuit in this case that is like this if I draw the equivalent circuit, then it should be like this.

(Refer Slide Time: 18:31)



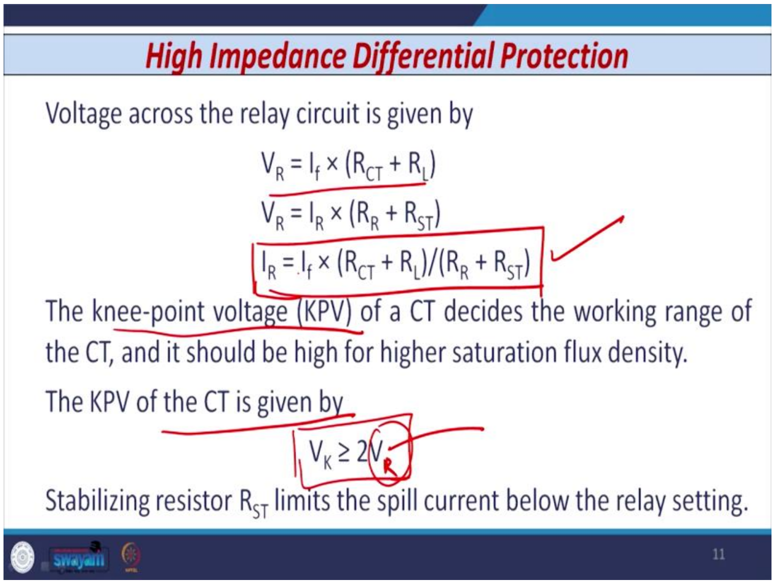


So, you can see that here the CT which is healthy that be acts as an open circuit and along with that you can see that you have the RCT and RL1, so again from here you have the RCT and the RL1 lead resistance one, this is our CT1, let us say it is 1. Then you have the point A where you have connected the relay along with stabilizing resistance, so you have some stabilizing resistance R ST and along with the relay.

Now, relay coil has some impedance, let us say the resistance RR plus some XR and then you have this point B, so this is connected to B. And see this CT2 is saturated, so it acts as a short circuit so along with this you have RL2 and RCT2, so here you have the RCT2 and RL2 and this is connected somewhere here.

So, if I consider the current that flows through this RL2 and RCT2, which is there somewhere here, that is the fault current, let us say the small if and if I consider the current flows through the relay, let us say that is I capital R, then this current should be your IR. Keep in mind the voltage across this that is let us assume VR at this we have already assumed that is the VR.

(Refer Slide Time: 20:22)



So, if I just write down the equation in this case, then the equation that is given by this VR, so you can see this voltage VR across the relay here that is given by fault current if, this is the fault current referred on CT secondary side multiply by this 2 resistance that is RCT2 plus RL2. And similarly this VR that should be also equal to the current flows through the relay that is capital IR into the stabilizing resistance RST plus the impedance of the relay.

Now, see this inductance of the relay is very small, so this XR you can say that is very very lower than the RR so we can neglect the XR, so we can write only the RR. And if I compare this two equation, then you see that the IR into RST that is stabilizing resistance plus RR real resistance that is small if into RCT2 plus RL2, now I write it RCT2 and RL 2 as RCT and RL, so this RCT plus RL.

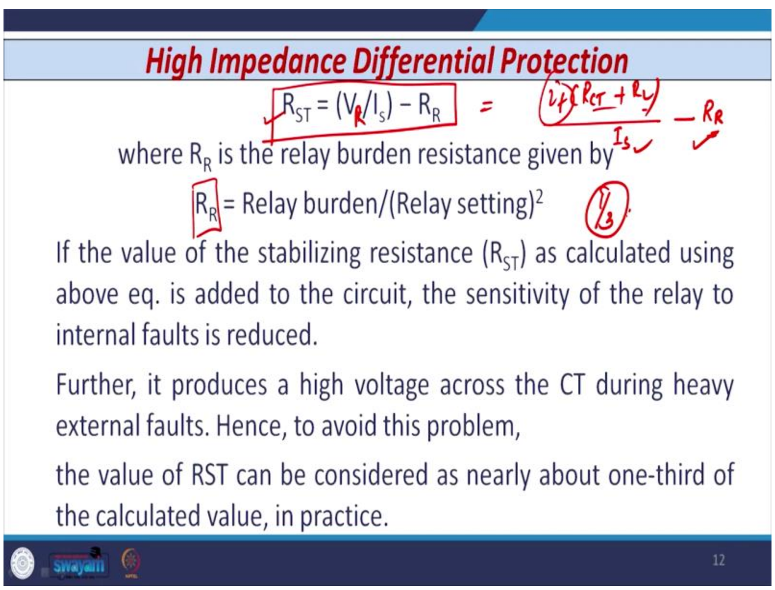
So, you have if I just find out the IR, the current that flows through the relay then that is if RCT plus RL divide by this value that is stabilizing resistance plus relay resistance like this. So, from this equation, you can easily find out that if I increase the value of RST, the resistance of the stabilizing resistor then the value current through the, that is the relay, relay current reduces. So, IR reduces, so that means sensitivity of the relay reduces, that is why I told you that one of the biggest disadvantage of this type of scheme is the sensitivity of the relay reduces in case of internal fault.

So, we can easily derive this equation that is the current that flows through the relay that is IR. Now, the another important point when we consider high impedance differential protection scheme that is known as the knee point voltage, it is also known as KPV. So, KPV of the CT that is going to decide what is the working range of the CT, whether CT will operates in the linear region or the CT enters the saturation region.

So, in this case, we need to ensure the stability of the relay of this type of when we connect the resistor in series with the relay coil, we need to ensure the stability particularly in case of external fault or a heavy through fault. So, KPV of the CT that is given by the equation VK that is greater than or equal to VR, this VR that is nothing but the this is capital VR that is nothing but the voltage across the relay coil.

So, we have already discussed that the voltage across the relay that is VR and this value that if you double it then that means voltage that is the CT can easily withstand and it can operate in the linear region, otherwise it enters in the saturation region.

(Refer Slide Time: 23:40)

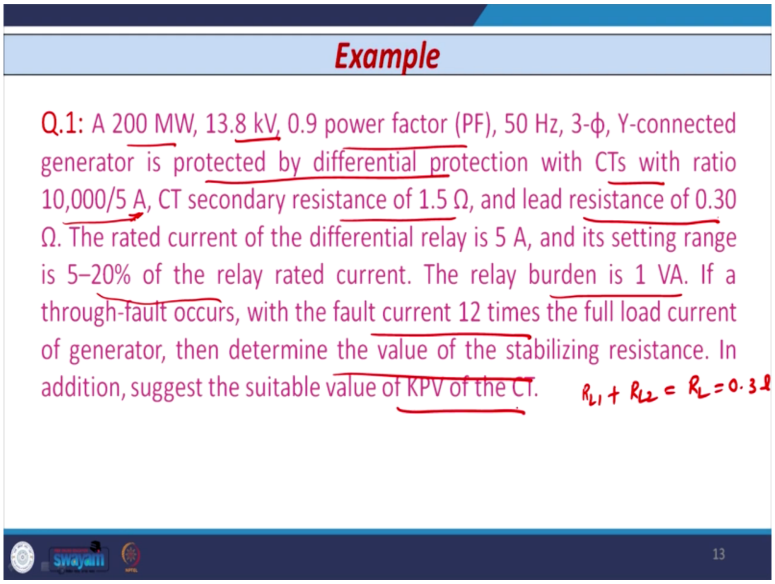


Now, if I want to find out the value of stabilizing resistor, then we can also easily find out using this equation, if you just find out what is the value of RST then you can easily find out the value of RST. So, the value of RST that is given by like this which is equal to the voltage across the relay that is the nothing but the if RCT plus RL that is the VR divide by is that is the current flows through the relay or as the pickup value or setting of the relay minus the RR, that is the resistance of the relay.

This RR resistance of the relay depends on the burden of the relay, so relay burden divide by the what is the relay setting or set value of current square you can easily find out the value of RR, so you can put it here, Is is known RCT RL is known, if you can easily find out, so you can easily calculate the value of stabilizing resistance. So, whatever value you calculate and obtained using this equation this value if I connect along with the coil of the relay in series with the coil of the relay, then the sensitivity of the relay reduces tremendously.

So, to avoid this in actual field, we are not going to connect the value of RST as we have calculated using this formula, but instead of that whatever value obtained from this formula, you take one third of that value and that value you are going to connect with in the in series with the relay coil in actual or practical field.

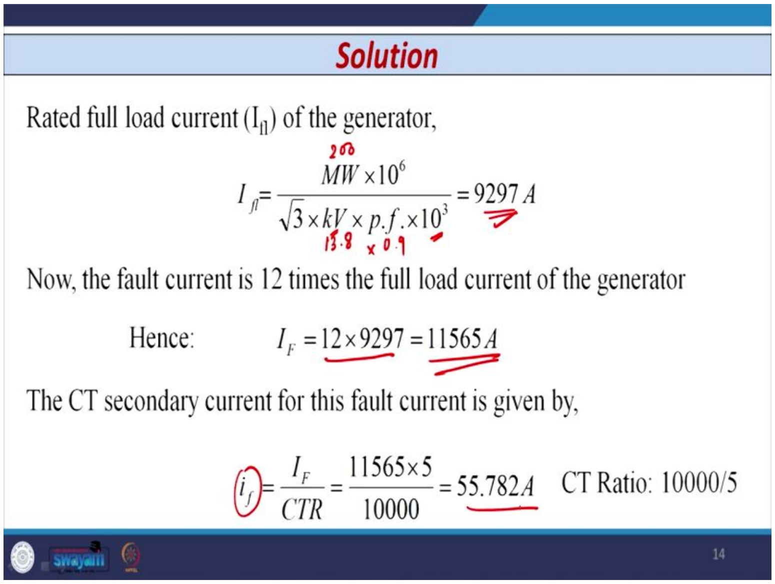
(Refer Slide Time: 25:14)



So, to understand this let us solve one example. So, let us consider a 200 megawatt, 13.8 KV, 0.9 power factor, 50 hertz, 3 phase star connected alternator or generator and that is protected by differential protection scheme with the CTs having the ratio 10,000 by 5 ampere, the CT secondary resistance is 1.5. Ohm and the lead resistance it includes both RL1 and RL2 total together that is 0.3 Ohm, so 0.3 Ohm that is your RL1 plus RL2, which is nothing but the capital RL that is 0.3 Ohm.

The rated current of the differential relay is given that is 5 ampere that is the CT same as the CT secondary current and its setting range is 5 to 20 percent of the relay rated current. The burden of the relay is also given very less 1 VA and if the any through-fault that is the external fault occurs with the fault current 12 times the full load current of the generator, then you need to determine the value of stabilizing resistance. You have to also suggest the knee point voltage of the city. So, let us solve this.

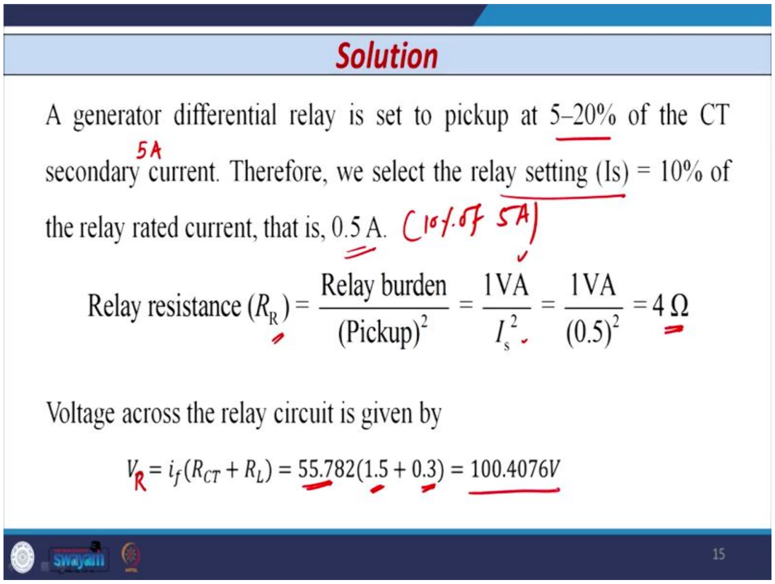
(Refer Slide Time: 26:26)



So, if I just calculate the full load current of the generator then full load current of the generator that is given by using this value data 200 megawatt 0.9 power factor, so you can easily calculate this megawatt rating is 200 into 10 raise to 6 divided by root 3, this KV value that is already given 13.8 KV into 10 raised to 3 multiply by power factor that is already given that is 0.9. So, if you calculate, then the value comes out to be 9297 ampere.

Now, it is already given that the fault current that is the 12 times the full load current of the relay, so if I find out the fault current that is 12 times this value 9297 ampere then the fault current comes out to be the 11565 ampere. If I convert this value for fault current on the CT secondary side having the ratio 10,000 by 5 ampere then the small value of fault current on CT secondary side that is 11565 multiply by 5 divided by 10,000. So the current comes out to be 55.782 ampere.

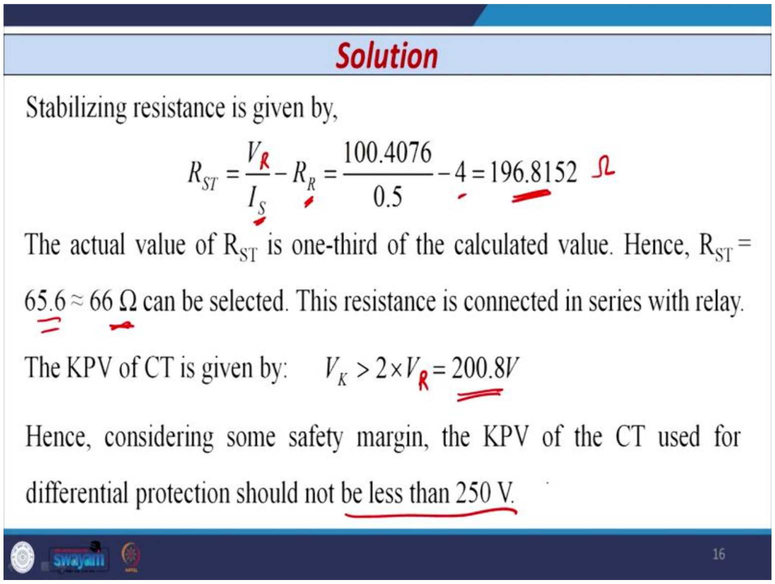
(Refer Slide Time: 27:39)



Now, the range of the differential current that is given as 5 to 20 percent of CT secondary current and this CT secondary current that is nothing but the 5 ampere. So, if I select 10 percent value roughly that is the Is relay setting current or set value of the relay current than 10 percent of the 5 ampere so that comes out to be 0.5 ampere, so this is 10 percent of 5 ampere. You can select any other value say 5 percent, 15 percent, 20 percent it depends.

Now, let us find out the relay resistance RR which is the burden of the relay divide by this setting, so 1 VA divide Is that is 0.5 square so you can calculate RR that is forum. So, let us find out the voltage across the relay, let us say V capital R that is if into RCT plus RL, so if is already known that is the value 55.782, so this is nothing but the 55.782 into RCT is also given 1.5 ohm RL, RL1 plus RL2 that is given 0.3, so you can calculate this value 100.4076 volts.

(Refer Slide Time: 28:51)

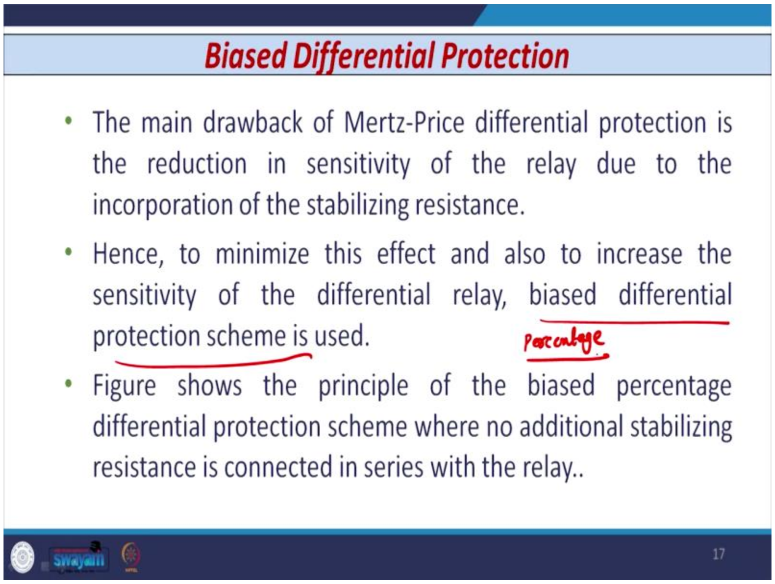


So, the stabilizing resistance you can easily calculate by the equation stabilizing resistance RST is equal to VR that is if into RCT plus RL, we already calculated earlier 100.4076 divide by Is that is the set value of current 05 ampere minus the relay resistance that is 4 ohm. So, you can calculate the RST that is 196.81520 ohm. So, as I told you when you connect actually this value the value should be taken as one third of this value, so if you take one third of this value, then it comes out to be 656 ohm, so roughly you can connect 66 or 70 Ohm in series with the relay coil as a stabilizing resistor.

Now, let us find out what is the KPV, knee point voltage of the CT. So, as I told you the KPV of the CT should be greater than or equal to two times the voltage across the relay coil, so then this should be equal to 2 times the VR, so VR is already calculated 100 then if you multiply it should be roughly around 200 volt. So, considering some safety margin, you can easily say that the knee point voltage of the CT used for this differential protection that should not be less than the 250 volt, so it should be always more than 250 volt, otherwise the CT may enter in the saturation region.

So, the next scheme that is known as the biased differential protection scheme, so we know that the main drawback of the circulating current or merge price differential protection scheme, that is the sensitivity of the relay should be reduced if I connect the stabilizing resistor in series with the relay coil, because as I told you through the equation that if I wish to increase the value of stabilizing resistance, which comes in denominator then the current through the relay that is the IR that is reduces. So, we have to compromise or optimize between whether what value of resistor we need to connect and what sensitivity we need. So, there is always a optimization between these two values.

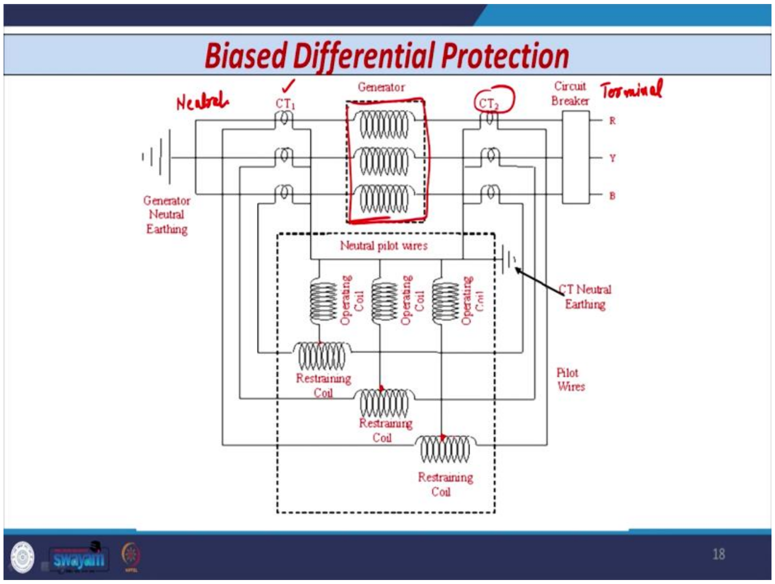
(Refer Slide Time: 31:10)



Hence to minimize this effect and to increase the sensitivity of the differential relay and the next point or scheme that is known as biased differential protection, sometimes it is also known as percentage differential protection scheme, so this is also known as percentage differential protection scheme.

So, let us discuss what is the percentage differential protection scheme or what is the biased differential protection scheme, in which no additional stabilizing resistance is required in series with the relay coil as we have discussed or considered in case of high impedance differential protection scheme.

(Refer Slide Time: 31:44)



This is the diagram of the biased differential protection scheme. So, you can see here I have shown the 3 phase diagram, so again this point is the neutral of the generator which is grounded and the other point that is nothing but on this side that is the terminal of the generator. So, you can easily say that if we wish to protect the winding of the generator then on each side we have connected neutral side, we have a seat set of CT, let us say CT1 and on the terminal side of the generator we have the CT set of CTs, let us say CT2.

And the secondary of this set of CT1 and CT2 that is connected to the directly to the relay and you can see in earlier case we have only the operating coil of the relay, however in this case, we have the restraining coil and it is connected, so operating coil three operating coils that is connected midpoint of the restraining coil, so such that as we have already discussed in case of transformer protection when we connect like this, then the two settings are available for this relay biased differential relay and these two settings are we have already discussed in case of transformer protection, we will also discuss these two settings in the next class.

So, in this class we have we started our discussion with the what are the main causes and consequences of the fault in the generator large generator, we need to protect the generator, if you avoid the outage of the generator, we started our discussion with the differential protection scheme in which we have discussed the circulating current differential protection scheme and we have also discussed high impedance differential protection scheme and we have also calculated one example based on the high impedance differential protection scheme.

2And then we started our discussion with the biased differential protection scheme. The settings of the biased differential protection scheme we discuss in the next class. Thank you.