Power System Protection and Switchgear

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Lecture 12

Current Based Relaying Scheme-VII

So, let us discuss further. In the last class, we started our discussion with the example based on ground relays and we have already calculated the plug setting of all the 3 ground relays. That is in this case R1, R2 and R3. So, now let us calculate the time dial setting of relays R1 R2 and R3. Now, as I told you the TDS of relay R1, sorry R4 that is given as 0.1.

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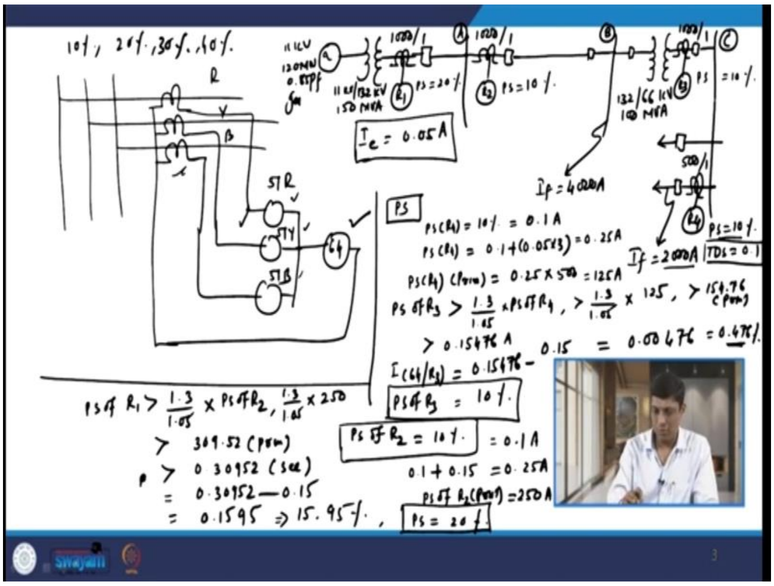

So, and along with this, the fault current level immediately after the relaying point R4 that is also given as 2000 ampere. So, this is same as the bus level or fault current at bus C. So, utilizing this let us calculate. Let us coordinate the relay R3 with relay R4.

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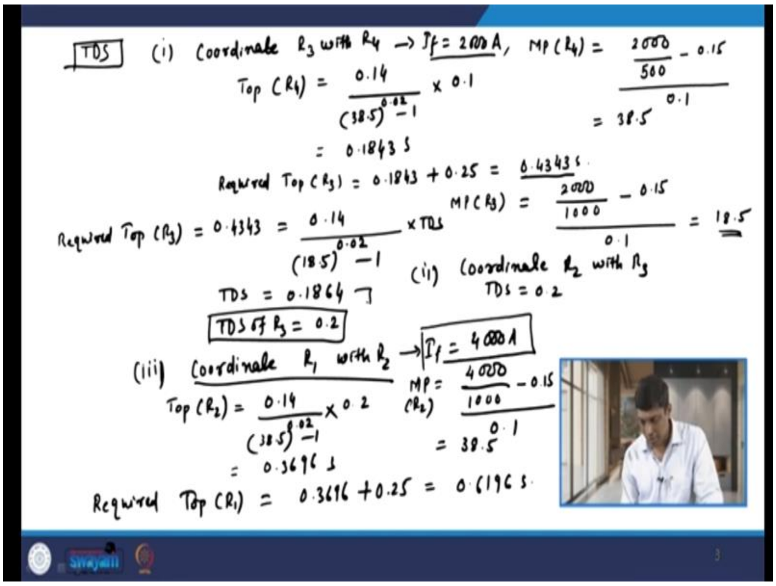

So, we need to calculate the time dial setting and let us first coordinate. Relay R3 with relay R4 and this is at fault current equal to you can see here that is 2000 ampere. So, this is at 2000 ampere. So, now let us first calculate the multiple of pick up current of relay R4 at 2000 ampere current.

So, 2000 ampere is default current divided by CT ratio of relay R4 that is 500. So, this is 500 and again, the only difference between phase relays and ground relays is here I need to subtract this whole value with the excitation current of 3 line CTs so that is 0.15 and whole divided by the plug setting of relay R4 that is 10 percent so that is nothing but the 0.1.

So, if I calculate this value, the MP of R4 that comes out to be 38.5. So, if I use this value, then we can calculate the time of operation of relay R4 that is equal to 0.14 divided by MP. So, MP is 38.5, raise is 2.02 minus 1 into TDS. TDS of R4 that is given as 0.1, so we can calculate the time that is given by the 0.1843 second.

So, we can say that the required time of operation of relay R3 that is given by 0.1843 second plus 0.25 which is the minimum coordination time interval. So, the value comes out to be 0.43 second. So, for the same fault current level that is 2000 ampere let us calculate the multiple of pick up current for relay R3.

So, that is again nothing but the 2000 ampere that is the fault current and CT ratio. So CT ratio of R3 that is 1000, so you can divide it with 1000 minus again the we have to subtract the whole value from CT excitation current divided by plug setting of relay R3. So, plug setting of relay R3 that is 10 percent. So, that is nothing but the 0.1. So, if you calculate this value, then that comes out to be 18.5.

So, we can say that the required time of operation of relay R3, which is equal to 0.4343 second that is equal to 0.14 divided by MP that is 18.5. We have already calculated. So, 18.5 raise to 0.02 minus 1 into TDS. So, if I calculate this, the TDS value comes out to be 0.1864 so we can select the higher range of this next range available that is 0.2. So, TDS of relay R3 that comes out to be 0.2.

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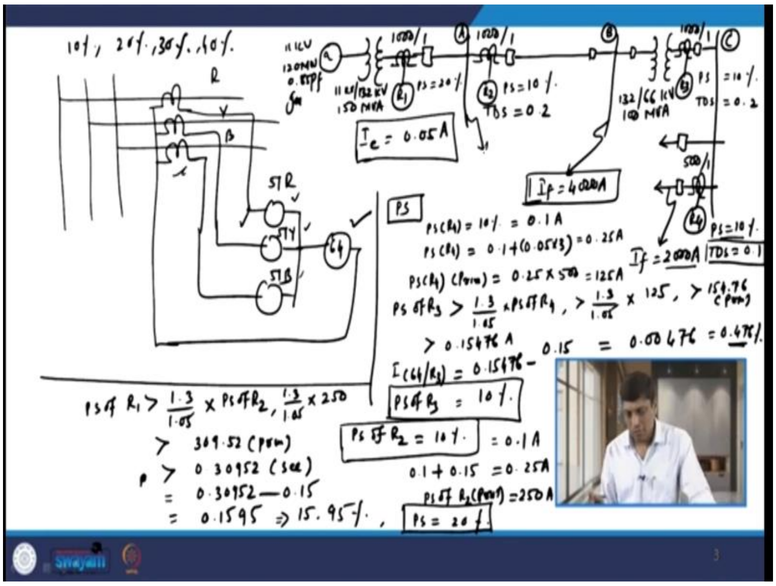

So, in previous case, let us write down the TDS here that is comes out to be 0.2 for relay R3. Now, as I told you earlier, when we coordinate relay R2 and R3, there is a star delta transformer between relay R2 and R3. So, there is no need to coordinate using the whatever procedure we have described earlier when we coordinate R3 and R4. So, we can directly write down the TDS of R2 that is same as TDS of R3.

So, we can write down here TDS of R2 that is 0.2. This is similar to the TDS value of R3, even you can consider the lower value also, lower than 0.2. If I want to select 0.1 0.5, you can easily consider that value because between these 2 relays star delta transformer is involved so we can independently set the relay on this side.

So, that is one thing. So, now let us coordinate relay R1 and relay R2 for the fault current level. That is 4000 amperes. Actually when we coordinate relay R1 with relay R2, we need to consider the fault current level at this bus but as in this case, it is not mentioned or given so we have to coordinate relay R1 and R2 for the fault current level. That is 4000 ampere. So, let us coordinate relay.

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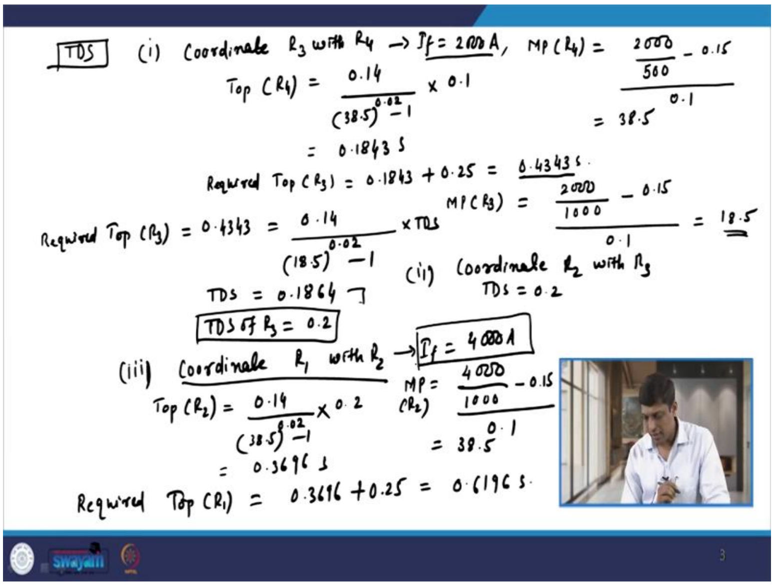

Now third case, that is the let us coordinate relay R1 with relay R2. Our second case that would be we coordinate relay R2 with relay R3 and in that case we have directly set the value of TDS of relay R2 that is 0.2 same as the relay R3. So, let us coordinate relay R1 with relay R2. So, this is at fault current level. That is 4000 amperes.

So, let us calculate first the multiple of pick up current of relay R2 at 4000 ampere. So, 4000 ampere divided by CT ratio of relay R2 so that is the 1000 by 1 ampere CT and its plug setting is 10 percent. So, this is 1000 minus excitation current of 3-line CTs that is 0.15 divided by 0.1.

So, if I solve this value, then that comes out to be 38.5. So, using this value, let us calculate the time of operation of relay R2 that is equal to 0.14 divided by MP that is 38.5 raised 2.02 minus 1 into TDS. TDS of R2 we have already decided that is 0.2. So, if I use this value, calculate this then the value comes out to be 0.3696 second. So, with this value, let us write down the required time of operation of relay R1 that is equal to 0.3696 plus minimum coordination time that is 0.25. So, this value comes out to be 0.6196 seconds. So, for the same fault current level that is 4000 ampere let us calculate the multiple of pick up current of relay R1.

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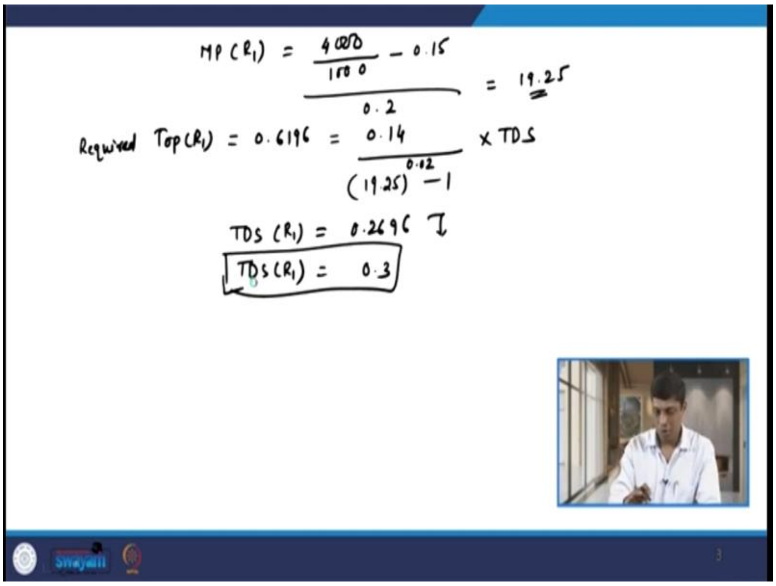

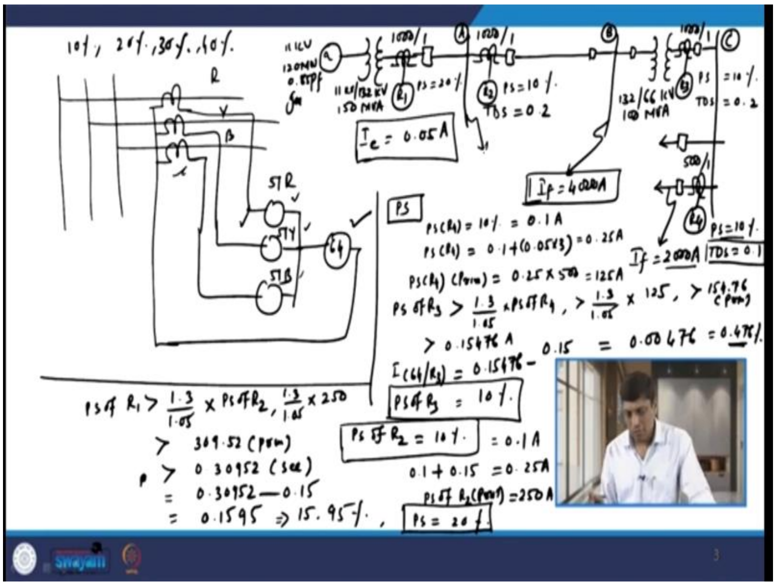

So, that is 4000 ampere divided by the city ratio of relay R1 that is 1000 by 1 and its plug setting that is 0.2. So, this is divided by 1000 CT ratio minus 3 excitation current of 3 line CTs divided by its plug setting of R1 that is 0.2. So, this comes out to be 19.25. So, with this value, let us calculate the required time of operation of relay R1 that is equal to 0.6196. We have already calculated here 6196.

So that is equal to 0.14 divided by MP that is 19.25 raised to 0.02 minus 1 into TDS. So, the TDS value of relay R1 that comes out to be if I calculate it 0.2696. So, the next higher range available that is 0.3. So, TDS of R1 we have decided that is 0.3.

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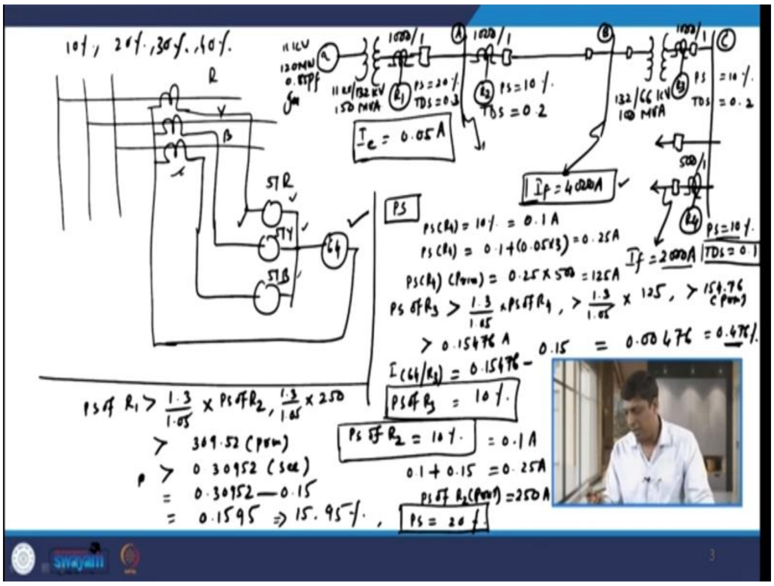

So, in the previous case, let us write down the TDS of R1 that is 0.3. So, we have already calculated the value of plug setting as well as time dial setting of relays R1, R2 and R3 based on the plug setting and time dial setting of relay R4 that is already given.

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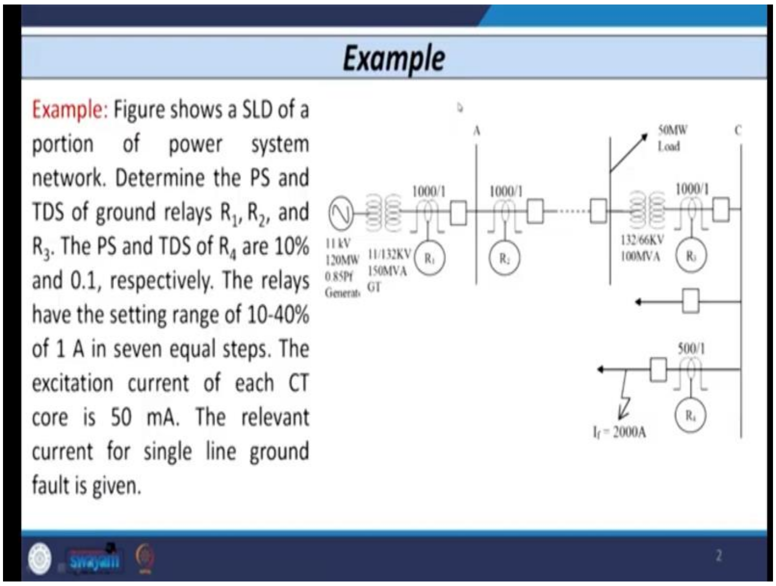

So, with this background, now let us further proceed. Now, till now whatever relay we have considered that is this relay is bi-directional relay. That means this relay operate when current exceeds its pickup value or plug setting irrespective of direction of the current. Whether current flows in one direction or the other if current exceeds pickup value relay operates.

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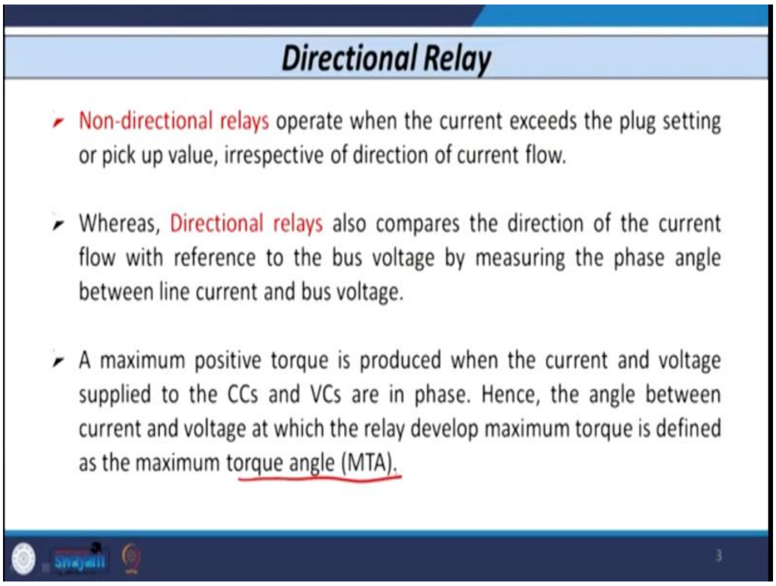

Now, the next case let us consider the relay that is known as directional relay. Directional relay operates on the same principle. If current exceeds the pickup value or plug setting and the other end logic is also included if the current direction is according to the set direction or given direction. So, if both these conditions are satisfied then directional relay operates.

So basically, directional relay compares the direction of current that is the line current and the bus voltage and basically it compares the angle between line current and bus voltage. So that is known as phase angle and based on this, directional relay decides whether the operation is required or blocking is required. Now, when we consider the directional relay as it compares the phase angle between voltage and current, so it is basically a 2 input relay. So, we have to give the one input from the current coin.

So, that is the CT secondary we have to give and the other input we have to give from the pressure coil or voltage coin so secondary of that, that has to be given to the relay coin. So, relay coil of directional relay takes 2 input that is from current transformer and the other is from the potential transformer or CVT. So, the angle between current and voltage at which the relay develops or directional relay develops a maximum term that angle that is known as maximum torque angle and usually it is denoted by MTA. So, empty is basically nothing but the angle or the maximum torque angle or the angle at which at which relay produces maximum torque. So, with this background, let us consider one vector diagram.

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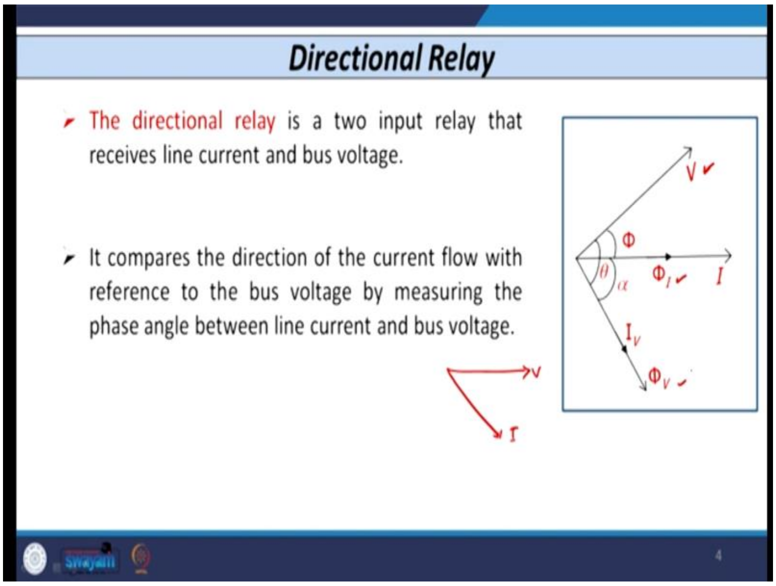

So, here you can take the reference vector as a current. You can also consider the voltage as a reference vector. So, if I consider the voltage as a reference vector, then the whole diagram that becomes like this, so your this whole diagram that will be tilted. So, if I consider this then you can see that the whenever you give current to the current coil the current I Flows and it is going to set up a flux that is known as phi I.

When you give the supply to the voltage coil or pressure coil, which is highly inductive in nature then the flux is set up. This flux is almost at 90 degree with reference to the voltage vector so we can see that if the flux set up in the pressure coil or voltage coil is phi V then this phi V is almost at 90 degree with respect to the voltage V.

So, the as we, I told you earlier that the directional relay compares the angle between the line current and the bus voltage so that angle we need to calculate and that based on that angle based on the input given to the relay, one from current coil and other from voltage coil, the torque is produced and that torque we need to find out.

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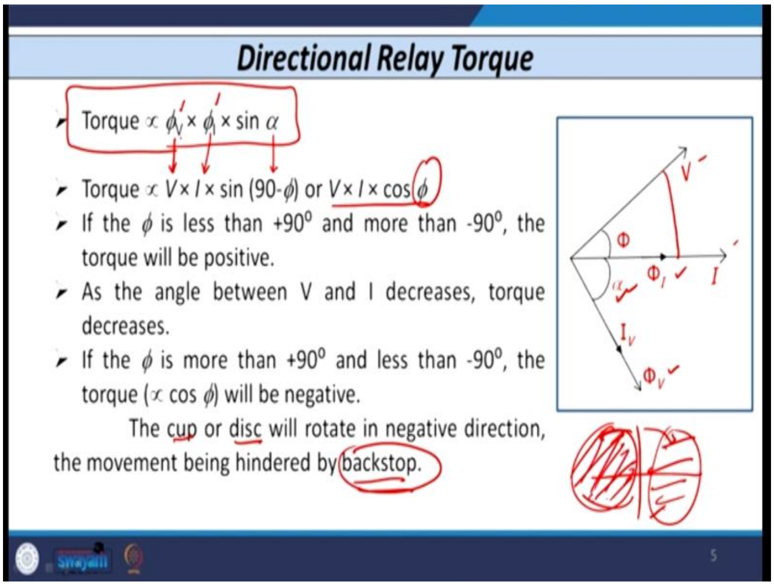

So, when we find out this value, the torque bit that is given by the 2 flux produced interaction of 2 fluxes, one is produced by current coil that is phi I and another is produced by the voltage coil or pressure coil that is phi V. So, if I consider this phi V then you have the phi V. Here if I consider the phi I then you have the phi I here and the angle between these 2 fluxes phi V and phi I that is nothing but the alpha that is this angle and sign of this alpha. So, this this equation is going to produce the torque for directional relay.

So, this torque if I write down in terms of voltage and current then this phi V that is proportional to voltage so here we can write instead of phi V we have V. The phi I that is proportional to current I and the angle between this V and I, see in earlier case angle between phi V and phi I that is alpha but now as we have changed this equation in terms of voltage and current so angle between voltage and current that is nothing but 90 minus alpha that is this angle. So, that we can write down here sine of alpha. Instead of alpha we can write down the 90 minus phi so that we have return.

So, ultimately our equation becomes torque produced in the directional relay that is given by V I cos phi. So, if this value of phi which is known as phase angle between voltage and current, if it is less than plus 90 degree and more than minus 90 degree, then the torque produced that will be positive.

So, if I just draw this 4 quadrant, if this phi that is less than plus 90 degree and more than minus 90 degree, then in this region the torque produced that is positive. On the other case if the angle this phi is more than 90 degree and the less than minus 90 in this region then the torque produce is negative, and the directional relay does not operate or does not initiate any action.

So, we can say that as I told you earlier that when we use the directional relay we can use this relay as a induction cup relay or we can use it as a induction disc relay. So, depending upon the rotor whether we want cup type or the disk type, this will rotate in particular direction that is only in positive direction. If current is in in this region in positive direction, and then relay operates, otherwise relay blocks. So, in this region really blocks because they have provided on the moving contact with that they have provided one device known as backstop. So, backstop is basically meant for the relay does not move in opposite direction particularly in this region.

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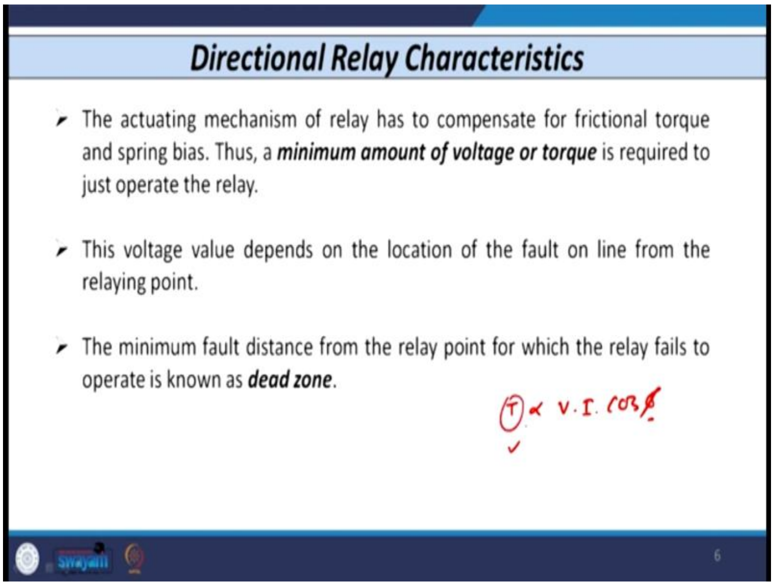

So, we know that whenever the we have discussed that the torque produced by the directional relay that is given by T which is proportional to V into I into cos of angle between V and I that is 5. So, now the torque produced by this relay that is maximum when phi is what is the value of phi, when phi is 0, cos phi is 1 so the torque produced by the relay directional relay that is maximum.

So, when this angle between this voltage and current that is phi which is 0 then minimum angle is there, then the torque produce that is highest and we want that whenever fault occurs the torque the torque produced by the directional relay that should be maximum. So, based on this let us discuss the torque characteristic.

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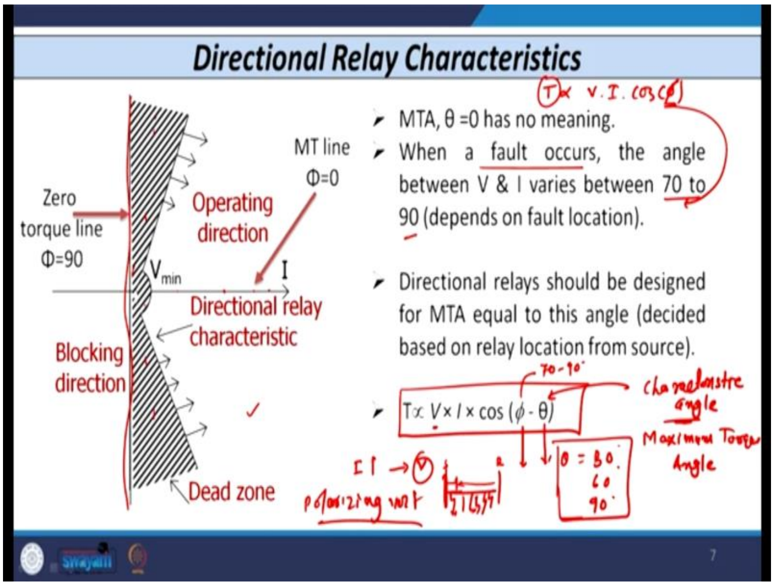

So, if I draw the directional relay, if I wish to draw the characteristic of directional relay, then this is the characteristic of directional relay. You can see that if I use I as a reference vector then this line, this point here all these points you will have the it is known as maximum torque line because the angle between voltage and current that is 0 and hence, you will get the maximum torque. Opposite to this perpendicular to this, this line that is known as the 0 torque line because the angle here between voltage and current that is 90 degree. So, cos 90 is 0 so torque produced by the relay that is also 0.

Now, whenever fault occurs, we know that always we wish that the directional relay produces maximum torque and it operates when actual fault occurs. Whenever actual fault occurs the angle between voltage and current that is power factor angle that varies from 70 to 90 degree and that depends on the location of fault. So, whenever in our earlier equation T is proportional to V into I into cos of angle between V and I that is phi. If phi varies in this range, 70 to 90 degree, so torque produced that is very small. So actually, we want that whenever fault occurs torque produced by the relay that is maximum.

So, if we achieve this then we have to modify our equation of torque and which is given by the V I cos of phi minus theta where theta that is known as the characteristic angle. Characteristic angle sometimes it is also known as the maximum torque angle. It is also known as the maximum torque angle. So, in this equation phi that is not in our hand because it depends on location at what location fault occurs, but usually it varies in the range of 70 to 90 degree.

So, this phi we can adjust based on the connection of CTs and PTs. How we can do the connection of CT and PT based on that we can change this value of theta. So, this theta we can consider normally in actual field they consider 3 different values. One is the 30 degree, another is the 60 degree and the other one that is the 90 degree.

So, depending upon what value of theta we consider and if suppose the value of phi varies from 70 to 90 degree and if I consider theta that is 60 or 90 then the torque produced by the relay at the time of fault that is maximum and relay always operates. Now, here in this characteristic as I told you earlier that the directional really measures the angle between voltage and current.

This sometimes indicates that there is no meaning of magnitude of voltage and current but it is not like that. Magnitude of voltage and magnitude of current that plays an important role for the operation of directional relay. Whenever fault occurs, the magnitude of fault current is very high.

So, as far as current is concerned that is not a question, but whenever fault occurs the value of voltage plays an important role if fault occurs in the line near the remote end then as we move further towards the sending end this is receiving end, so as the location of fault moves from receiving end to sending and the value of voltage changes.

If fault occurs very near to the sending end the voltage developed by the relay or given to the relay that is very small and as voltage given to the relay coil is very small so torque produced that is also very small. So, in this case for any directional relay we need to give some voltage quantity as a reference and that minimum voltage quantity is required by each and every relay.

That voltage quantity is known as polarizing voltage. Polarizing voltage. So, if I use electromechanical relay static relay, then the polarizing voltage that should be sufficient or very high but now it is as I told you earlier that we are utilizing digital relay. So, the polarizing voltage that should be very small. For digital relay, it is usually 0.1 to 0.5 volt whereas in case of electromechanical and static relay, you need to give some value like 50 100 volt or 40 volt minimum.

So, that relay coil will require this much voltage for the successful operation of the directional relay. So, as I told you for from the sending end some minimum distance is there. If fault occurs in that distance from descending end very small distance maybe in terms of meters, then the voltage developed by the relay or given to the relay coil that is very small and relay is not able to operate so that zone that is known as dead zone of the directional relay. So, that is indicated by this shaded portion here. You can see all this shaded portion. That is the directional dead zone of the directional relay and if fault occurs in this case, then relay is not going to operate. So, this is all about the directional relay.

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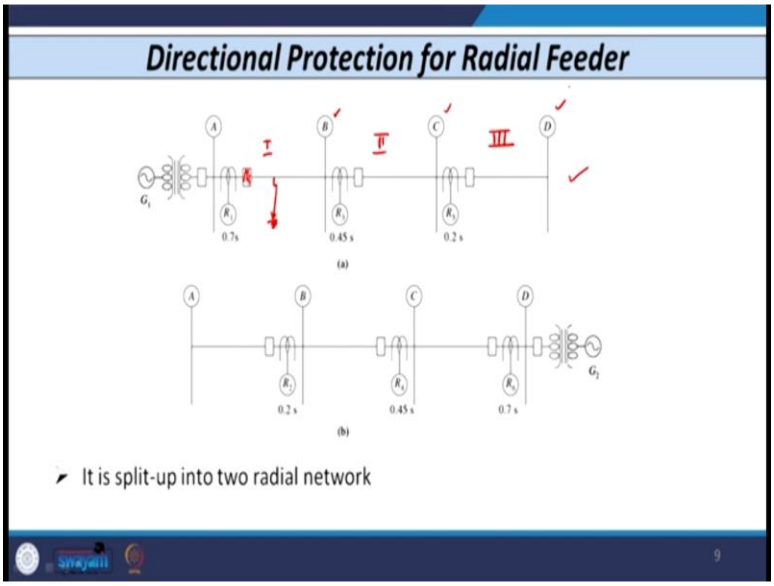

Now, when we consider the directional relay how we can apply this directional relay to our earlier multi section radial feeder network. So, if I consider the multi section radial feeder network you can see this upper figure you have the similar case. We have considered the 3 sections. So, this is our section 1, this is section 2 and this is section 3.

So, we have 3 sections and it is a radial network because source is connected on one side, load is connected on other side and we have 3 relays situated in each section. 1 2 3. R1 R3 R5. Now, if I consider, suppose a fault occurs somewhere here in this section then obviously relay R1 has to operate and it gives signal to the breaker and this breaker. This breaker that becomes open.

If this is the case then you can see that the supply at bus B, bus C and bus D that are interrupted. So, this is again is the selectivity criteria of the protection system. So, if we move on any uninterrupted power supply at all the 4 buses A, B, C and D, then we need to change the concept.

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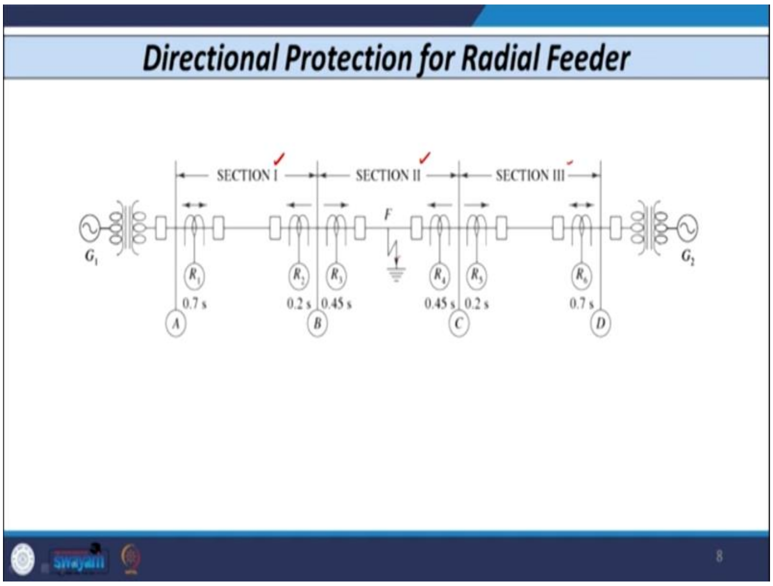

So, what we need? We need to give the, we need to use the 2 relay for each section. So, this is our section 1 and I have used 2 relay R1 and R2. This is our section 2 and I have used the relay R3 and R4 and this is our Section 3 where we have used 2 relay the R5 and R6. So, any fault occurs in section 3, relay R5 and R6 has to operate. Any fault occurs in section 2, R3 and R4 has to operate as a primary relay and any fault in section 1, relay R1 and R2 has to operate.

Now, if this is the case, suppose then how to set or decide the time plug setting and time dial setting of this 3 6 relays R1 to R6. So, for that what we consider? We consider the multi section radial feeder fed from one end. So, we have you started with generator G1, we assume that this generator 2 is not there.

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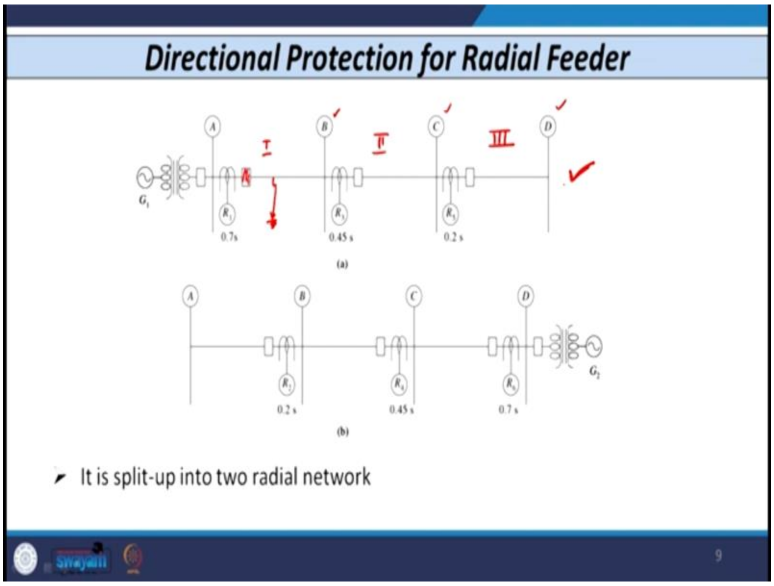

So, we have the circuit like this upper portion part A where R1 R3 R5 are there and in the second case we started, we assume that generator 1 is not there and we start with generator 2 so we have the circuit that is from R6, R4 and R2. Now, let us assume that how to decide plug setting and time dial setting. Plug settings are decided based on full load current of the feeder. Time dial setting you have to decide in this case. First we decide R2 then R3 and then R1.

So, let us assume that time dial setting of R5 is 0.2. R 3 is 0.45 and R1 is 0.7. Same way, you can decide the plug setting and time dial setting of the other lower circuit. That is B. So, you first decide time dial setting of R3 R2 R4 and then R6. So let us assume its value is 0.2, 0.45 and 0.7.

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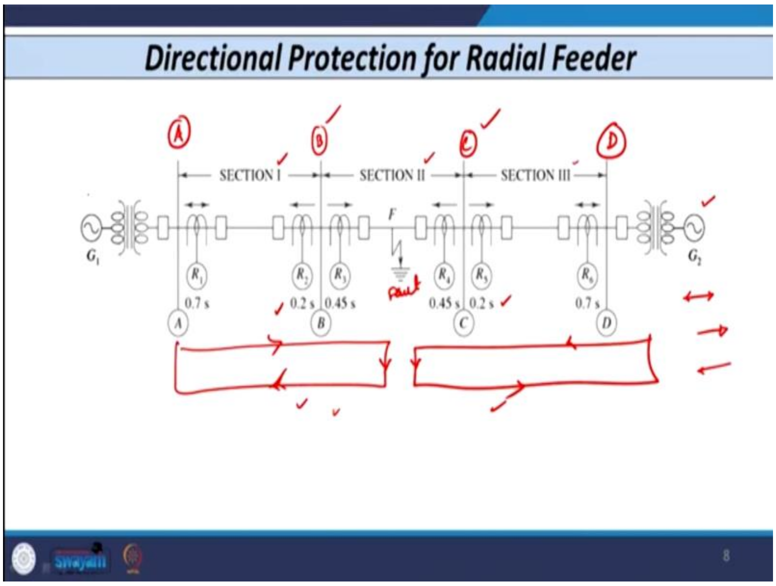

So, if I assume this value, so I have written this value here and now let us assume that fault occurs in section 2. So, this is the fault point. Fault occurs at this section. So, in this case what will happen? One fault current path is from generator G1 so it is from G1 to F and the other fault path is from G2 to F.

So, one fault path is like this here and the other fold path that is like this from G2 to here. So, if this is the case then obviously relay R3 and relay R4 has to operate because fault is in section 2 and this 2 relay act as a primary relay and they have to operate but as I told you the fault current path is I have shown from both the side.

So, in this case, time dial setting of relay R5 that is smallest and here also the time dial setting of relay R2 that is smallest so for a fault in section 2 R2 and R5 has to operate and disconnect the section 2. Now, this is okay section is disconnected but again, this is against the selectivity criteria of the protection system because fault is in section 2 and R3 and R4 has to operate instead of these 2 relays R2 and R5 will operate. So, whatever load you have connected at this bus, say, this is bus B and bus C, this is bus A and this is bus D.

So, whatever load you have connected here obviously, this loads are inter power so this loads are interrupted. So, that means we need to add some additional feature. So, if I now assume that the relay R4 and relay R5, relay R2 and relay R3. If these 4 relays are directional relays then the problem that is solved. Whenever I assume bi-directional relay about the relay it is shown by this arrow and whenever I assumed the directional relay about the relay to show the direction like this or like this. So, you can see that relay R3 and R4 in section 2 both are directional and direction of current I have shown away from the bus B and away from the bus C.

So, what is the meaning of this? That means if fault occurs and if current through relay R4 is the direction of current from relay R4 is away from the bus C and if current exceeds plug setting then relay R4 operates. That is the meaning of the same way for relay R3, R2 and R5. Now, see if this is the case any fault occurs at F in section 2 then for this 2 fault path you can see that the relay alpha is not going to operate because the fault direction of fault current is opposite to that which is mentioned about the city of relay R5. Same way relay R2 is also not going to operate because the direction of fault path that is opposite to that of the direction mentioned above the city of relay R2.

So, this clearly shows that the our problem that is solved and we can easily now coordinate the relay all the 6 relays and no maloperation that can be obtained. So, this is one case how directional relay that is helpful for the multi-section radial feeder fed from both the end. So, here you have generator here and you have generator here also. This is one of the application of directional relay.

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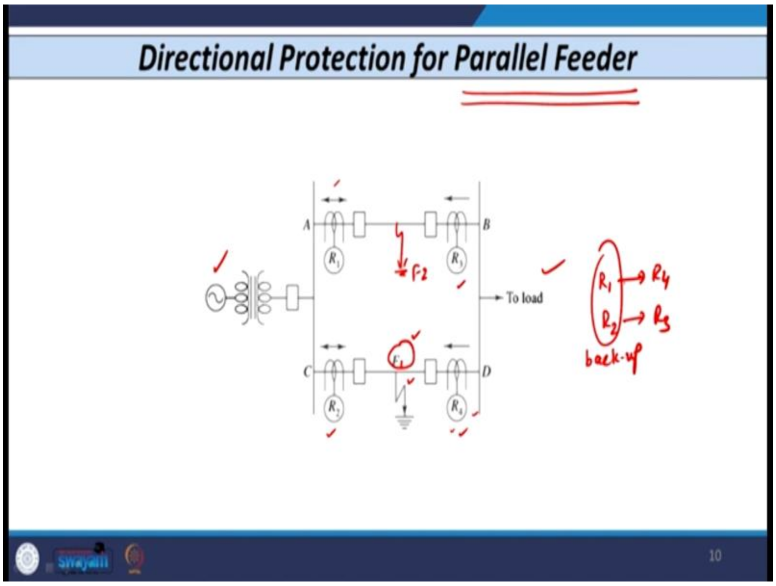

Now, let us see what is the other application of directional relay. So, other application is when we use parallel feeder at that time directional relay plays an important role. So, for that let us consider one parallel feeder fed from one end. A generator is on left hand side load is on right hand side and we have the four relays connected. Now, suppose if fault occurs at this point, let us say, this fault is F1 in this section so obviously one fault path is from generator through relay R2 through this fault like this so relay R2 has to operate. The other fault path is from generator to A to B to D to the fault point.

So, relay R1, R3 and R4, all 3 relays comes in picture. So, let us say that suppose relay R4 and relay R2 has to operate for a fault at F1. So, are R2 will definitely operate because the fault path from generator is minimum through relay R2. So, R2 will operate but for the other fault path where R1, R3 and R4, all 3 relays are involved.

So, in this case, R4 has to operate then R3 and then R1. So, if I assume that relay R4 operates but before that R3 and R1 comes, so let us assume that relay R3 and R1 both are time delay and we can set these 2 relay and then relay R1, R2 and R4 will operate and disconnect this section but this is not correct because in case of fault in this section, let us say F2 what we need, R1 has to operate as the fault current path is from generator to R1 2 fault one path.

The other fault path is from generator to C to D to B to fault F2. So, in that case if I wish that R3 has to operate then R2 and R4 should be time-delayed. So, that is against our previous assumption when fault occurs at F1 earlier section. So, that means we need that relay R3 and relay R4 should be directional in nature.

So, we have given the direction. So, now if fault occurs somewhere in this section, then the relay R3 is not going to operate because the direction of fault path is opposite to that that is mentioned here. Relay R4 has to operate as the direction of fault path is similar to the relay R4 and R1 will provide backup to relay R4 so R1 will provide backup to R4 and same way R2 has to provide backup to relay R3.

So, this will provide backup. These 2 relay. So, if we set like this then the problem that is solved and so this is the one of the important application of directional relay. So, that means we want a particular relay to be directional or non-directional that depends on the fault current means at particular bars or particular point if fault current is reversed in both the direction then that relay should be directional in nature. Otherwise, the relay should be bi-directional.

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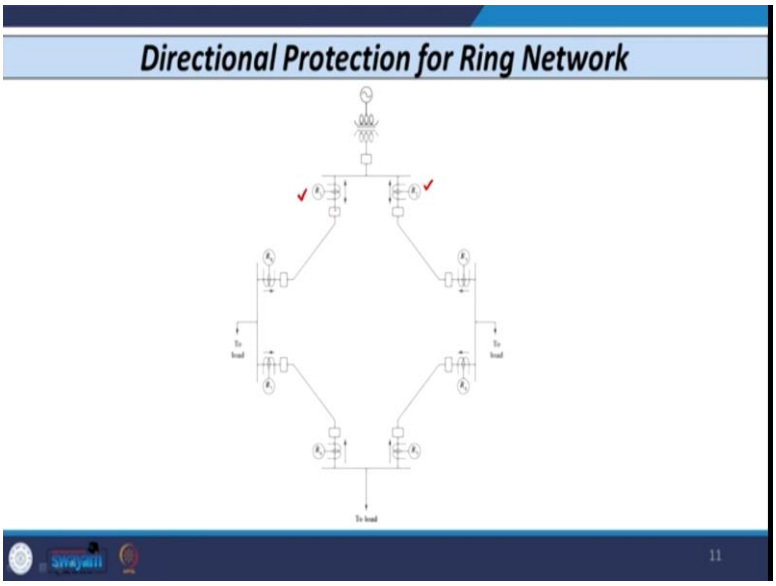

So, if I consider another example that is the ring main network. You can see that the now here all the relays are directional except the relay R1 and relay R2 because there is no chance of reversal of fault current. So, other relays which is situated total heat relays, 2 relays for 1 feeder. There are 4 feeders. So, all other relays are directional and direction is away from the bus.

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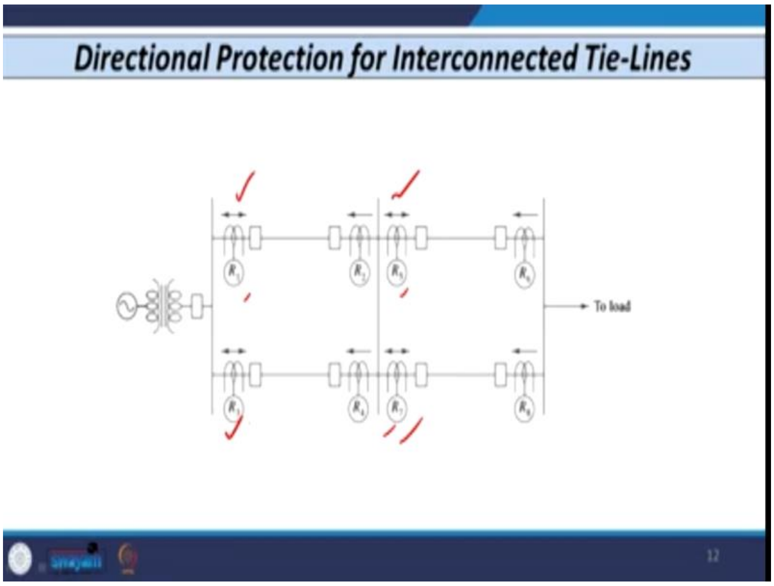

So, the other example is cascaded parallel feeder and you can see that here also all the the relays are directional accept these 4 relays because there are no chances of reversal of fault current for relay R5, R7, R1 and R3. Other relays are directional in nature.

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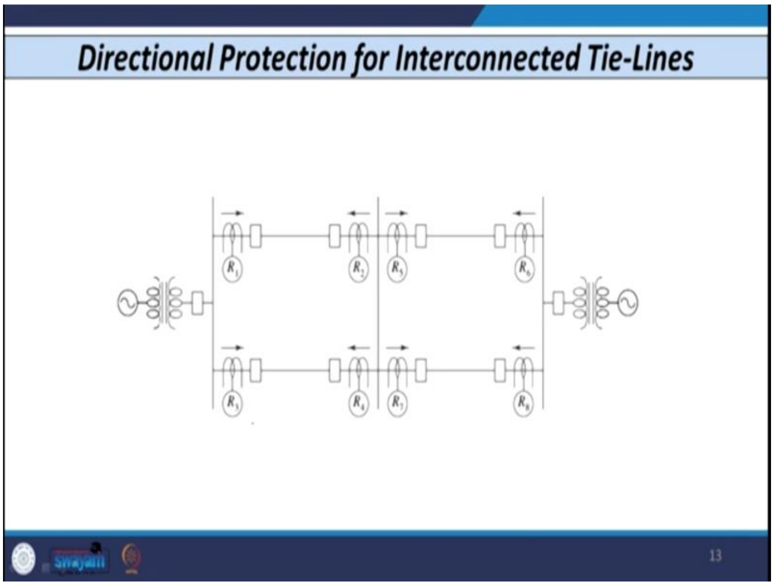

Same way if cascaded parallel feeder is fed from both the end then all these relays R1 to R8, all our directional in nature. So that is the another application.

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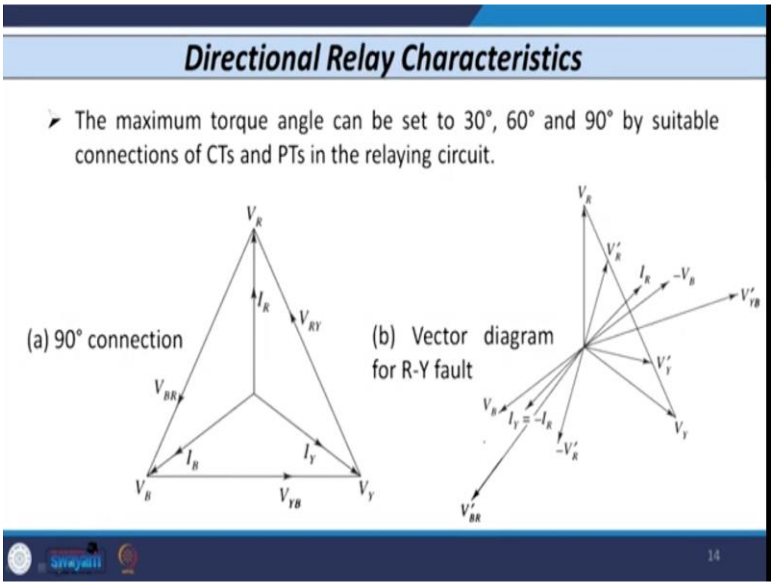

So, in this lecture, we have discussed earlier we started with our example on ground relays and then we started discussion for the directional relay. We have discussed how the directional relay works. What is the vector diagram of directional relay then we have discussed the characteristic of directional relay and then we started discussion with the what is the application of direction relay.

So, we have discussed its application in radial feeder fed from one end, radial fed from 2 end, ring network and parallel feeder, single parallel feeder and cascaded parallel feeder fed from one end as well as both ends. So, after this in the next class we will discuss the characteristic of directional relay and how we decide the characteristic angle theta or maximum torque angle theta for the directional relay. Thank you.