Power System Protection
Professor A K Pradhan
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur
Lecture 43
Line Differential – Part 2

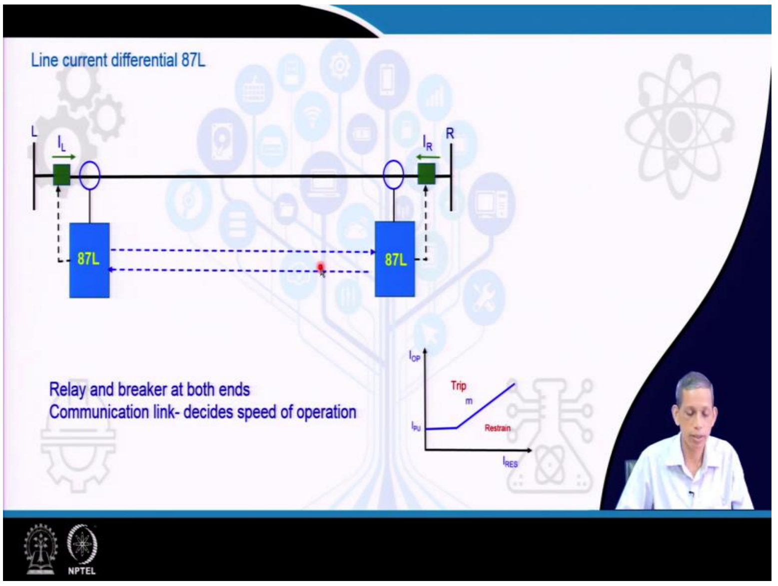
(Refer Slide Time: 0:26)

Welcome to NPTEL course on Power System Protection. We are continuing with Line Differential Protection.

(Refer Slide Time: 00:31)

In this lecture, our focus will be on transmission line or any feeder having tapped lines, differential protection for feeders that includes a transformer at the ends, we will go for the phase comparison protection, which also has the communication support and so.

(Refer Slide Time: 01:01)



So, continuing that, in the last class, we talked about 87L, the line differential protection with current signals from both the ends. Essentially, for a line or feeder, we need communication system, breakers at both the ends for an interconnected system.

In addition, these breakers are remotely placed we require differential relay individually at these two locations also. As compared to transformer, note here that in transformer we require essentially one relay, if it is interconnected system, breakers from both the ends, and if it is a radial system, breaker at one end only. In this case, breakers are large apart. So, we require for this breaker also, another relay.

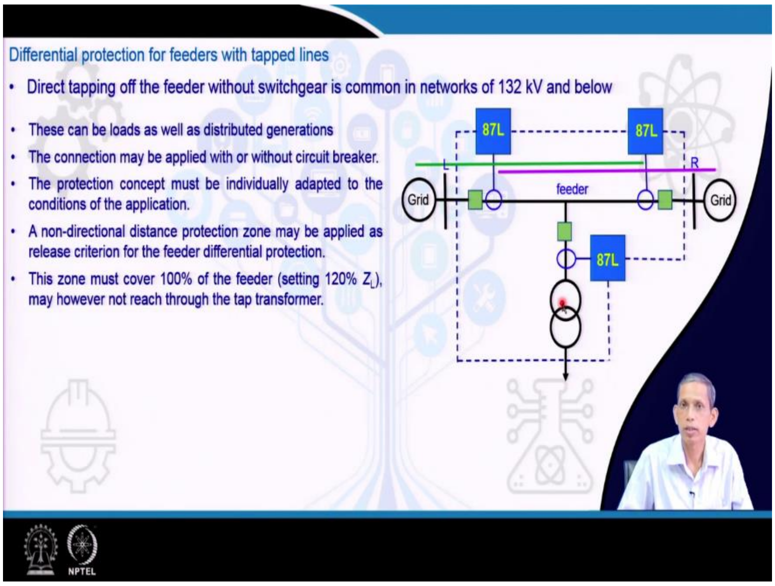
Furthermore, we say, that the trip decision and all these things, what we say the percentage biased differential relay, which we have already discussed for the line protection also, using the current information, the communication link is the backbone that decides the speed of operation of the relay.

Now, this side relay sends current information to the other end, let us say, the phasors, both real and imaginary part. In that case, this end receives and then processes it for a decision, either using ping pong or signal through the GPS and so. Thereby, communication associated delay that decides that at what time the corresponding differential protection will go for a processing.

Say, in one case, on the percentage biased differential relay perspective, it might decide every 5 ms, every 3 ms, every 2 ms or so go for this processing depending upon the communication link capacity.

In case of differential relay for transformer protection, that is localized, and therefore that can be pretty high speed. Whereas, the speed of operation of the differential relay here is decided by the capacity, capability of the communication link.

(Refer Slide Time: 03:41)



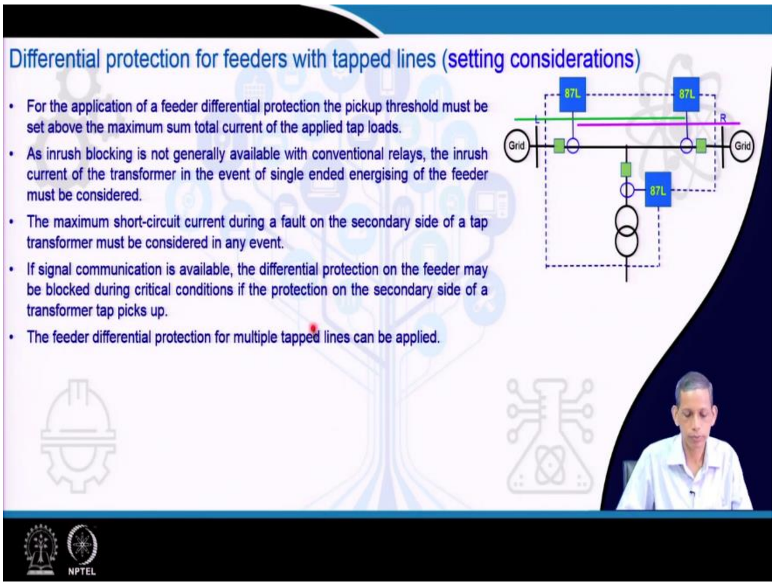
Now, let us go to the other applications of the line differential protection. First one, differential protection for feeders with tapped Lines. So here, this is the feeder or the line and we have a tapped line connecting a load, it may be today's renewable generation and so.

Now, the benefit here is that we do not require a substation or a breaker also. In that case, this additional current, if we apply the KCL here besides the L and R side current there is additional current here. Therefore, the differential relay must take into account that. Now, if we have communication information from all these terminals you can use the corresponding KCL and each relay can decide very efficiently but sometimes the communication link may not be available.

Then if there is no provision for the communication link or there may be a failure of communication, then how the corresponding relay will handle that situation. So, the connection may be applied to with or without breakers at this point, the protection concept must be individually adapted to the different situations. It is one, tapped line, there can be multiple tap lines also and so.

What is being done, is that a non-directional distance protection covering 120 % like we see here, from L and, this pink colour covers 120 % and from the R end, the green colour takes 120 %. Such a provision is there to initiate the corresponding 87L, to trigger the 87L for a fault in the line or so. This makes advantages to the system, considering that the corresponding impedance of this path is much higher, that is the impedance of the transformer becomes much higher or so.

(Refer Slide Time: 06:09)

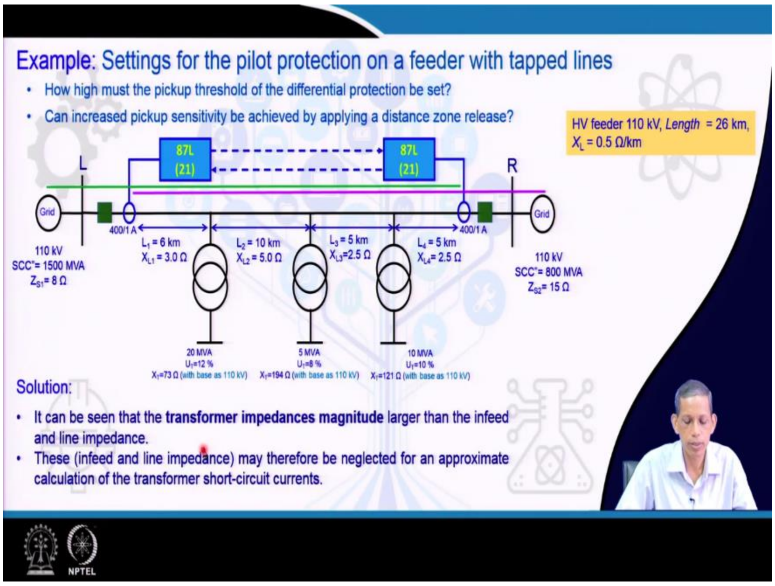


Now, how the corresponding settings in such a tapped line is being considered? There are the pickup setting and so, we will elaborate on that. For the application of this feeder differential protection, the pickup threshold must be above the maximum sum total current of the applied tapped loads.

To note, if there is no current information available at this end or this end, then the corresponding differential current for this load current must be greater than the tapped current. That is essentially, because that information is not available here. So, if you have multiple tap and all these things, then the corresponding maximum tapped current must be included in the pickup setting or so.

Now, what will happen whenever you switch on the corresponding system from one end because of some maintenance, at that time the inrush current will flow. This inrush current is very large amount, 5 times at times. So, that current will flow through this line differential relay, we do not bother about inrush, as we have already discussed in the last class, unlike that of a transformer protection. So, but here, there is a transformer associated, which will result in inrush current seen from this end and also from this end. So the inrush blocking is not generally available with conventional relays, but the inrush current result in the transformer. Therefore, now the point is that, can we address that in the pickup level of the differential protection that is the consideration. The maximum short-circuit current during a fault on the secondary side of a tap transformer must be considered. What we mean to say that, the fault here, the maximum fault current for just after the transformer must be considered for the differential relay setting, we will go to that example in the subsequent slide also. If signal communication is available, the differential protection on the feeder may be blocked during the critical condition. What we mean to say that, if there is signal available, so if the fault happens to be beyond the transformer, then in the load side of the transformer, then this 87L, both should be blocked. That is what we will have to say. So, that, avoid unnecessary tripping of the 87L and will make it more sensitive also.

(Refer Slide Time: 08:50)



Now, let us go to an example. It will clarify a better way, what do we intend to address here. So here, we have the grid connections, we have a feeder here and at different points of the feeder, we have taps connected via transformers 20 MVA, 5 MVA, 10 MVA transformers are connected. 3 transformers are connected through tap or the two tap lines, which are feeding to different loads. We have short-circuit capacity of this side grid and this side grid and this side grid.

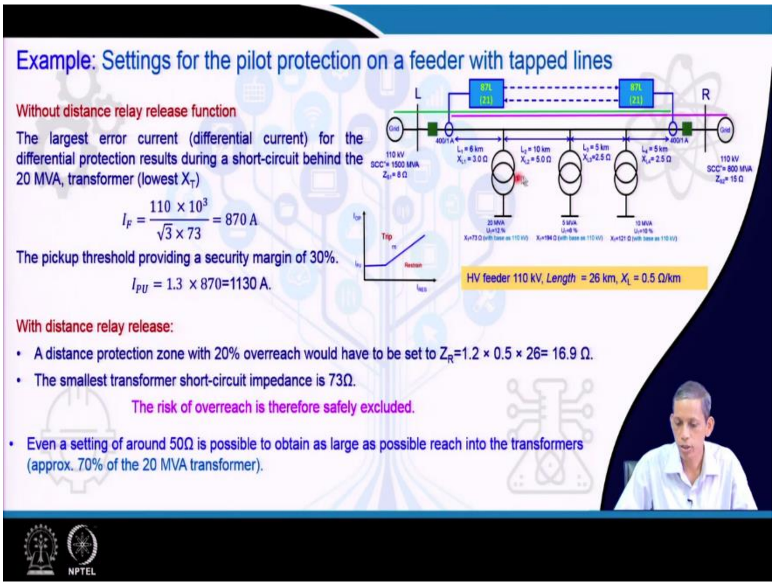
All the data given, line length of 6 km or 10 km or 5 km and another 5 km available here. 110 kV system, total length is 26 km feeder. How this corresponding differential protection for the feeder will be accomplished? So, what we have just discussed earlier. How much will be the pickup setting? Can increased pickup sensitivity be achieved by applying distance zone release? So, what we can say that 21 or the distance relay will supplement this 87L in a better way, that 120% setting what we are telling about. We will look into that perspective.

So now, we go to the solution for this system, this feeder protection in the presence of number of taps, we are talking about. Now, what is being seen here, that the, this line feeder are having smaller lengths. So, one straightforward, comparison on the impedances of the line of the feeder as compared to the impedance of the transformers. So, when you say, the largest capacity transformer that will have smaller impedance as compared to the other transformers.

So, this 20 MVA. So, for that, the corresponding transformer impedance happens to be 73Ω, referred to the 110 kV sight, line site, This is a having 194 Ω and this is having 120 Ω, referred to the all hundred 110 kV side. So, this means that the larger capacity transformer is having 73 Ω as compared to the positive sequence impedance of the transmission line, this is much-much higher. So, the transmission line is having 26 km and then, we have excelled is 0.5 Ω/km, (26 × 0.5) is the corresponding positive sequence impedance of the line.

So, that gives around 13 Ω. So, as compared to the corresponding transformer the impedance is much-much higher. The associated infeed and all these things also have high impedance, so as compared to the feeder impedance in general. So, in that condition, we will see, how we will proceed for the corresponding further calculation.

(Refer Slide Time: 12:06)



Now, let us say, we do not have distance relay support for the line differential, then what? In addition, if we have a distance relay support, then what? Now, the largest error current differential for the differential protection results during a short circuit behind the 20 MVA transformer. Load is one part, true, but here, the fault happens to be beyond the transformer, that fault current will be much significant.

So, we say that the capacity having largest, having a smaller impedance related to this other transformer. We create a 3-phase fault beyond the transformer, then we talk about the corresponding fault current will be most significant beyond the transformers in the tap lines.

Therefore, we consider the highest transformer capacity. So, that the corresponding fault just beyond the transformer (I_F) becomes equals to

$$I_F = \frac{110 \times 10^3}{\sqrt{3} \times 73} = 870\ A$$

So, that gives us 870 A for the 3-phase fault at just beyond the transformer, referred to feeder side or the 110 kV side. Taking a factor of security margin of 130 % extra, so

$$I_{PU} = 1.3 \times 870 = 1130 \text{ A.}$$

You can take any other margin depending upon the choice. So, this is about that the pickup setting for these thresholds, this pickup in the percentage bias differential relay for the feeder protection 87L, this pickup settings will be accordingly 1130 A in terms of that perspective.

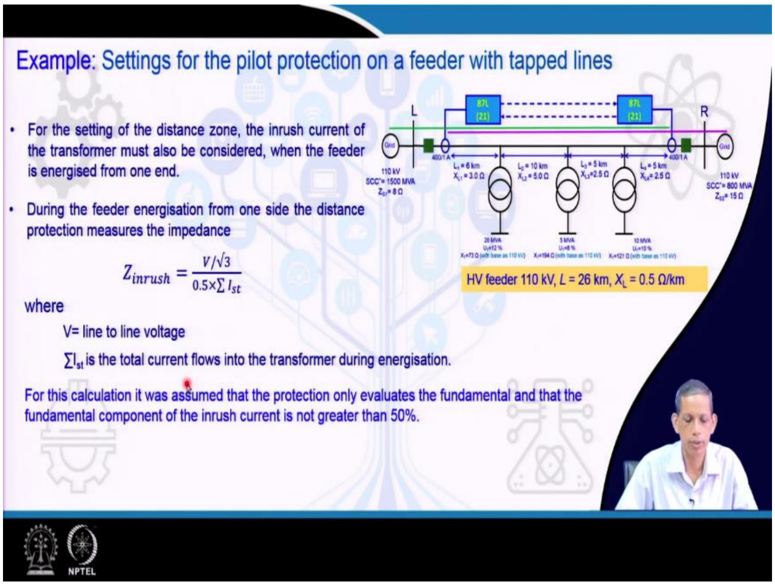
So, this is much higher than the total load of the system and so, that is what the pickup current should be satisfied in terms of that. Now, with distance relay, suppose this distance relay means it takes voltage information. So, if this corresponding relay there is voltage signal is available, and then we have again a distance relay, and the distance relay zone with 20 % overreach is 120 % Zone 2 kind of thing. For the feeder, it will be set,

$$Z_R = 1.2 \times 0.5 \times 26 = 16.9\ \Omega$$

But this 16.9 Ω is still much smaller than the 73 Ω that this impedance of this transformer referred to the 110 kV sides. Therefore, I am interested that the fault beyond the transformer will never be seen by the corresponding relay and that means that they will see in this line. So, what will happen, even if we take not 16.9 Ω, you can take higher will also absolutely have no problem.

What this corresponding distance relay does is that it supplements the 87L to be initiated and 87L based on its percentage by a differential relay can make a decision whether the fault is internal or not. That is what this 21 or the distance relay with the 120 % setting and so that helps in deciding the corresponding feeder protection in such a tapped arrangement.

(Refer Slide Time: 15:40)



Now, there is another factor about that, if we, so, if we say energize from one end or so, inrush current will flow. So, what is the inrush current level that we like to see during the feeder energisation from one side, let us see in this example, all three transformers will be switched on at a time.

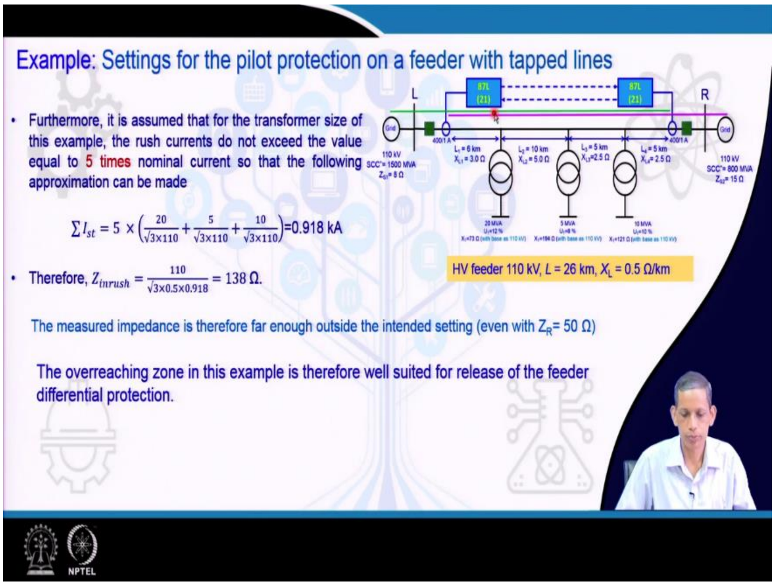
That means that all will be having inrush current. So, the corresponding at inrush situation, a current will flow and that do not exceed the value equal to 5 times nominal current. With the following approximation the total inrush current seen from one end of the protected transmission line is

$$\sum I_{st} = 5 \times \left(\frac{20}{\sqrt{3} \times 110} + \frac{5}{\sqrt{3} \times 110} + \frac{10}{\sqrt{3} \times 110} \right) = 0.918 \text{ kA}$$

Then we assume that the corresponding fundamental component of inrush is not greater than 50% as a large amount of other harmonics component particularly of second harmonic components are available in inrush current. Therefore, the corresponding impedance seen by the distance relay during this inrush situation is given by

$$Z_{inrush} = \frac{110}{\sqrt{3} \times 0.5 \times 0.918} = 138\ \Omega$$

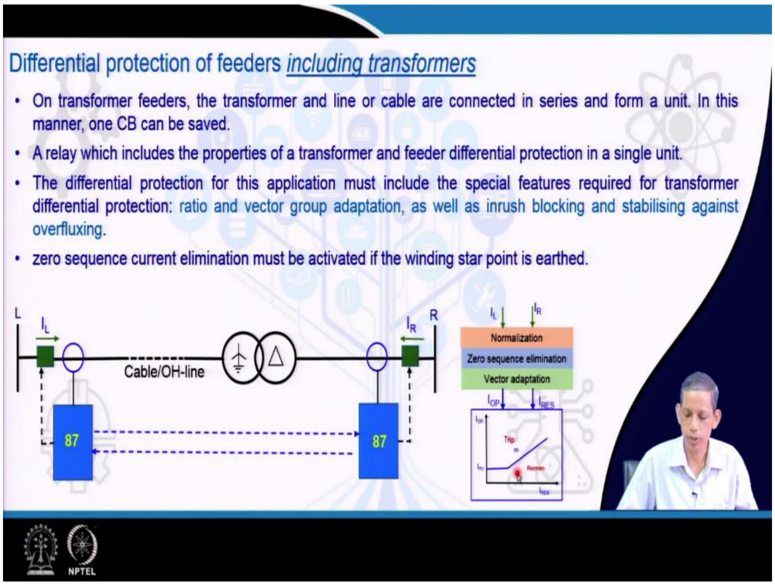
(Refer Slide Time: 17:09)



So, what it says? We have the impedance settings $Z_R = 16.9\,\Omega$ but here, during inrush situation the corresponding impedance as seen by this side or that side switching will result in 138 **Ω**, which is much-much higher even than the corresponding 73 **Ω** of the transformer. So, it means that for an internal fault, this corresponding impedance seen by the 21 relay is much smaller than that of during inrush or fault beyond the transformers.

So, this measured impedance outside the internal setting of that Z_R even if we set up very large value of 50 **Ω** or more so, and that will not give a problem. So, the overreaching zone in this example is therefore well suited for release of the feeder differential protection. It means that it supplements the corresponding differential protection in a better way. That, we like to say here that for tapped line, if the distance relay supplements the 87L, that become a better performing differential protection in that perspective with higher sensitivity and reliability.

(Refer Slide Time: 19:20)



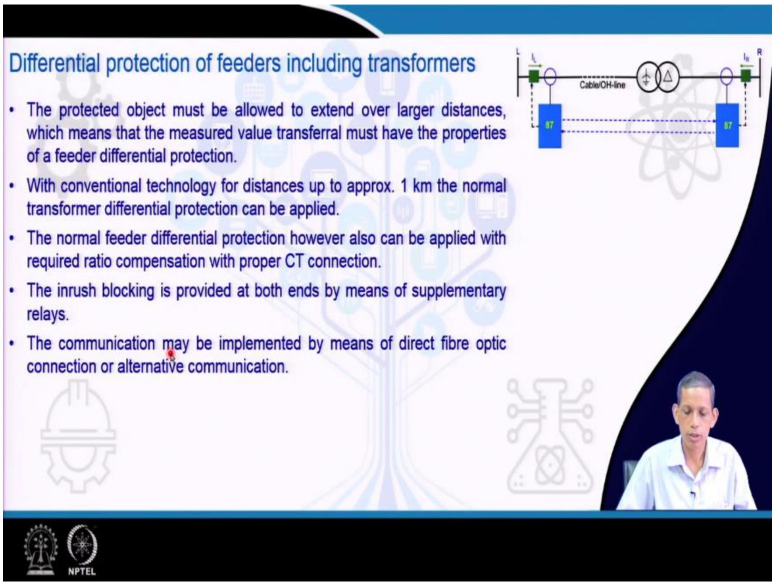
Now, we will go to this second example on line differential protections that includes transformers. So, what we like to say here, that we have a transformer connected by feeder or cable, small line length and then we have a bus here and here a bus here. So, like in case in general, in transformer case, we only, earlier we are considering only the transformer. Now here, a transformer is connected to an overhead line or cable, maybe of small length. So, we like to say that combined protection of this one, a differential protection. If you go for individual, that will be too expensive also. So, how the joint cable or the overhead line and the transformer can be protected by the differential arrangement, that is what the issue here in this case.

Again, we are talking about the percentage bias, this and then that this local end and the remote end I_L signal and I_R signal. And then we have is just like a line differential protection. Breaker here, breaker this end and we have individual 87L from this, both the perspective and so. But mind that what will happen? Because it includes transformer in series, so whenever we energize the corresponding transformer from any one end, there will be inrush current.

So, inrush will be problem. The other issue there will be a transformation of current, suppose fault happens to be there, the corresponding current here. So, those kind of angle transformation, angle phase shifting will happen just like a transformer. So, therefore, even they have a feeder here, so line differential protection only implies that is not adequate because of the presence of transformer. So, what are the things to be taken care, we would like to see here. The differential protection for this application must include the other features of the transformer, the trans-ratio transformation, the vector group adaptation, that matrix we remember for the phase shifting issue with both the sides CTs connected in star grounded that is what we practice today. And then the corresponding inrush blocking, overexcitation so on those issues must be inclusive. The zero sequence elimination is also essential, because when it is a star and delta and so, therefore, delta side, you can say that a line current will not be having zero sequence whether a star ground side will having zero sequence current also.

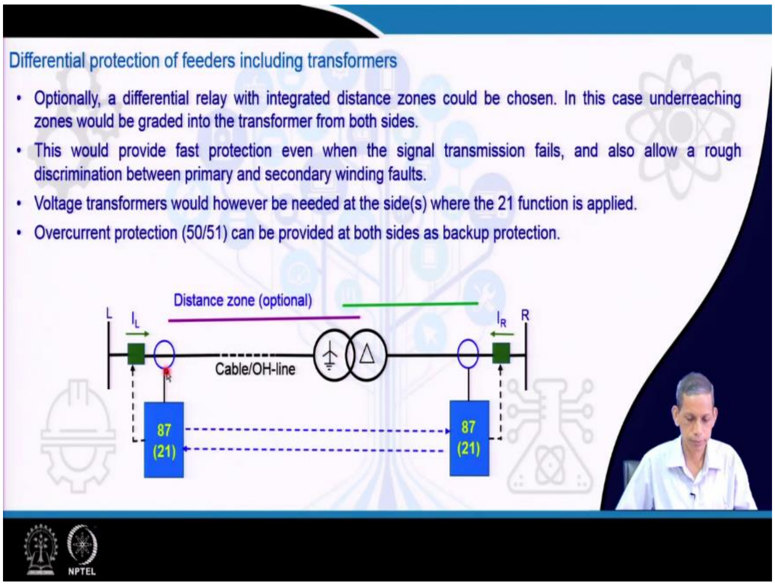
So, all these features must be there for such a protection that too mean to say that this 87 will be nothing but just like a transformer protection, but that includes a portion of the cable overhead line or so. So, these are the steps we follow to apply the corresponding combined protection of cable, overhead line and the transformer.

(Refer Slide Time: 22:33)



So, continuing that the protected object must be allowed to extend over larger distances, which means that the measured value transferral must have the protection. So, we require essentially, communication here, unlike a transformer here. Typically, this length cover and cable and so can be around 1 km or smaller than that. The normal feeder protection must be having applied to the required ratio compensation, proper CT connection, because you see here CT transfer ratio will be different unlike for a line feeder protection. Inrush blocking and communication are the added requirement for such an arrangement.

(Refer Slide Time: 23:18)

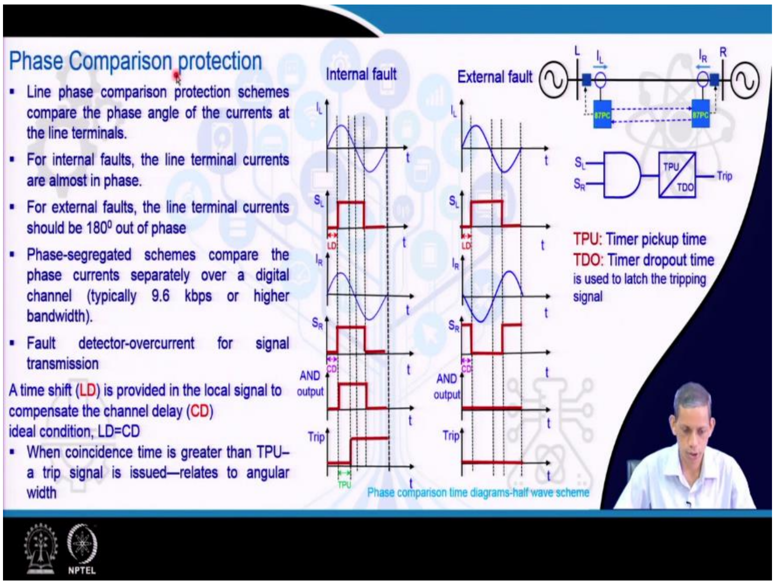


Now here, also we will say, that can we include distance relay supplementation like what we talked about in case of the earlier application also. Sometimes, you can say that a differential relay is integrated with distance zones, and in that case, underreaching zone would be graded. What is being done here in earlier example, we are talking about overreaching, now we are talking about underreaching kind of thing and what is being done, this will provide fast protection even when signal transmission fails in case of communication failure or so, that is the requirement in case of that.

So, what is being done? The corresponding impedance setting from this side, this one goes to one winding of the transformer and from this one it ends with another winding of the transformer. Thereby it ensures that the corresponding impedance of the transformer is larger. That indicates whether it is inside the transformer or not that is the advantage, we can explore if the corresponding 87L is supplemented by the distance relay perspective. However, we require voltage signal in terms of that also.

These kinds of arrangement also in case of communication failure can be supplemented by overcurrent protection 50 or 51 on both the sides. Mean to say that, today's relays are pretty powerful and they can integrate different principles altogether depending upon the availability of signal they can make a combined decision for the reliable operation of the protection scheme.

(Refer Slide Time: 25:06)



Now, we will go to another, the third aspect of this lecture on phase comparison protection. So, how phase can be compared in a communication system environment. We will again going to the same two bus systems L and R. Then we have the corresponding communication systems and these 87PC, PC for the phase comparison perspective, and how we can apply the concept where the phase can be compared, and then a decision on internal or external fault can be ensured, that we would like to see.

Here, unlike the corresponding phasor only the phase value of the corresponding signal value been transmitted from one end to another end in a feeder protection, this corresponding concept is here. The phase is compared in this perspective. So, what is being done here, the line phase comparison protection schemes compare the phase angle of the currents at the 2 terminals. For internal faults, the line terminal currents are almost in phase, and for external faults, the terminals currents are 180^0 out of phase.

So, the CTs as connected in the differential protection arrangement, Now let us come to the internal fault first, and then we will discuss about the external fault. Internal fault means fault inside this line and external fault is may be beyond R or beyond L to the left of L.

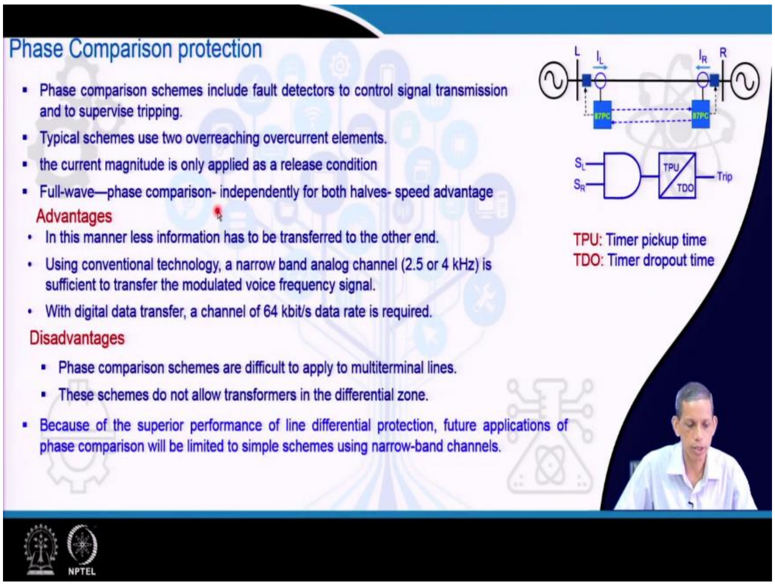
So, for the internal fault case, the local current becomes this current. What we do, we make the corresponding signal to be like this, at the zero crossing it start and we will make a delay of LD and what the LD means, we will talk about later on. Similarly, at remote end the corresponding sinusoidal signal is like this for the internal fault, because of the proper CT connection and then to make the square wave related to the corresponding zero-crossing point in the positive half. So, that is what the positive half cycle is being applied in this arrangement, what we are showing in this diagram, phase comparison diagram. Then, you make the AND of these two signals, the S_L and S_R, which are being transmitted. So, this L end receives the S_R signal from this end and the R side receive the S_L signals this square wave. Then this is nothing but tells about the positive half and the overlapping region is being there, so that of the S_L and S_R. The overlapping region happens to be this portion. So, that means this overlapping portion indicates the corresponding phase information of this signal and this signal. Therefore, the corresponding time information that is the corresponding square wave remains in the overlapping or coincidence region, indicated by the phase angle relation of I_L and I_R. Then, a trip decision can be issued. Now, come to the external fault case. If this is I_L, this becomes the I_R for external case because of the proper CT connection.

Now, the corresponding square wave generation, considering the positive half cycle and zero-crossing becomes equals to this and for this become this. So, the common the AND operation, becomes nil. Therefore, no trip decision in that perspective. Now, coming to this LD and CD. LD is the time shift being accomplished for the channel delay CD. So, what happens when you communicate from this end to this end, there is a channel delay. That channel delay must be taken care. Therefore, intentionally at the L end the corresponding signal is being shifted by a time of fixed of LD. We know that tentatively how much delay will be accomplished through this channel. Therefore, that is about the CD, according to the CD, the corresponding local signal is also shifted by LD. And that is what is being done.

Now, if the LD, and LD = CD at the local end, if that happens to be there, that is the ideal condition, then the corresponding phase angle information from this coincidence time can be obtained very accurately. So, when the coincidence time is greater than the timer pickup time TPU then based on the S_L and S_R inputs, the relay trips and if the coincidence time that is the AND operation, coincidence time is 0. If that becomes smaller than the TPU, then it is a no trip decision.

TDO is the timer dropout time, and this is used to latch the tripping signal for successful tripping and reliable tripping operation. So, then we see from this phase comparison principle, that the phase information of the current signal is being taken into a rectangular wave, the positive half and then, we can use the corresponding information, and by making an AND-ing operation, we know the corresponding coincidence time, that coincidence time is indicative of the corresponding phase between the two side signals and that is the name of the phase comparison protection emerge.

(Refer Slide Time: 31:16)

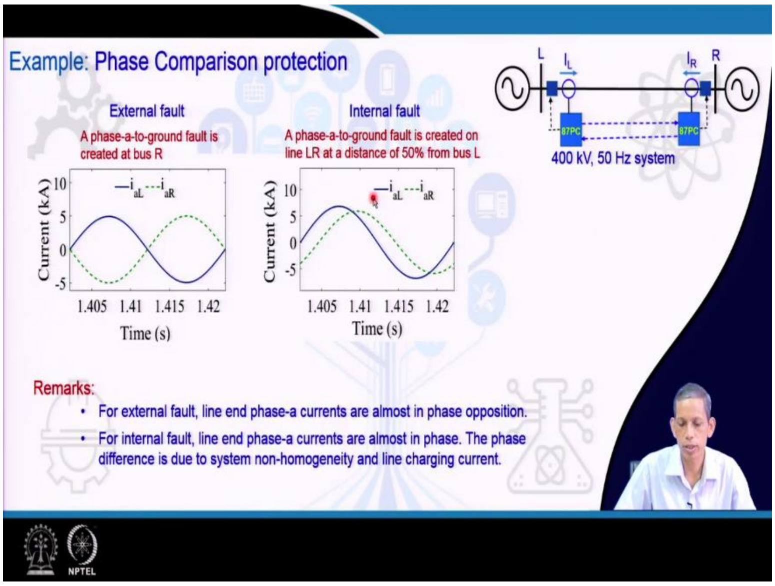


In continuing with this phase comparison protections; the phase comparison protections can include fault detection, including the overcurrent principle or an overcurrent principle to trigger the corresponding unit and that will make the corresponding decisions to be more reliable or so. When current becomes high, then only it should be activated and so. Then the reliability of the phase comparison can be in a better way. Now, that the other aspect in the earlier examples, we demonstrated only that the positive half, many applications in that domain relay use also both the halves. So, full wave is being used. In that case, positive is being compared with the positive, and negative half is being compared with the negative half and they are being done independently. So, positive will be compared with positive and negative will be compared with negative half and the using both the halves we can exploit the speed advantage. So, then we do not need to wait for the positive half, as you have seen in the earlier example.

The negative half also can do the coincidence time can be independently processed for the positive half and the negative half. Therefore, you can obtain that speed advantage for that perspective using the same timer logic, what we have already discussed in terms of that. The advantage of phase comparison is that we require very less information to be transferred to the other end. So, using conventional technology and narrow band analog channel signals, we can go up to 4 kHz or so, may be adequate using the voice frequency signal and so and with today's digital transfer, 64 kbps can also can be very successful using the information and so.

Some of the disadvantages of phase comparison schemes are difficult to apply for multiterminal lines. You remember multiterminal lines. So, for them, comparison of phase in terms of different current signals will be pretty difficult. These schemes do not allow transformers in the differential zone, what we have already addressed because there will be phase shifting and all these things, then you have to put the corresponding delta side to be star connection and star connection to be delta, so that phase comparison can be accomplished. So, those are the some of the disadvantage of this perspective. The superior performance of the percentage bias differential relay, which we have already discussed for feeder protection and all these things, application of phase comparison protection in the, its limited today. The only advantage, if the corresponding communication band is narrow, then we can use this phase comparison protections as a better options. There are already many old applications in this perspective, still in many systems we can find this but to the newer digital technology, all these things, this finds a limited scope.

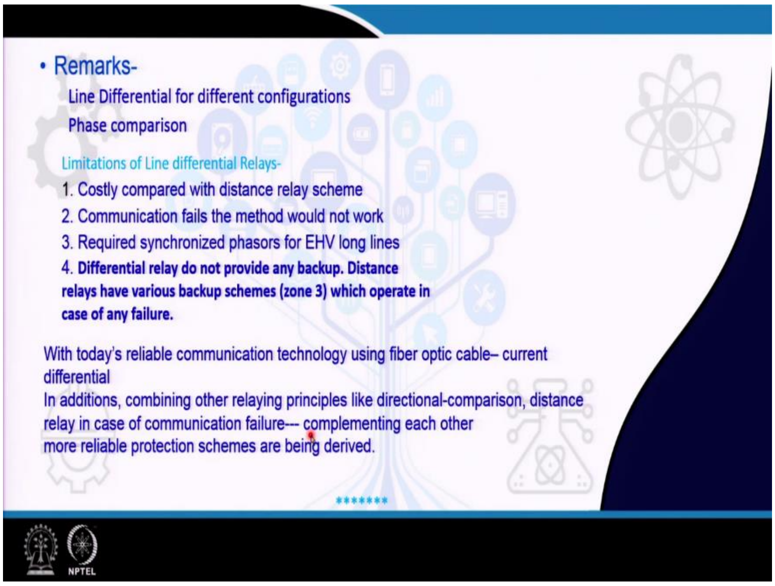
(Refer Slide Time: 34:40)



Now, example on this, so we have 400 kV systems. L and R are the two ends then for two cases, external fault case and this the blue curve is for the L end information, current information and the green dotted one is the R end information because this is an external fault case, they are out of phase and therefore the corresponding square wave of the positive half and here for that one the overall coincidence time will be 0 here and the corresponding fault can be detected easily.

Now, in case of phase-*a* to ground fault for the internal fault case, what happens, that current is being fed from this side and current is being fed from other side also. These are the two currents available from through the CTs. So here, the current of the two having a phase difference due to the non-homogeneity in the corresponding currents and the line charging current. That makes some deviation in angle but note that the phase comparison will still manage because of the coincidence time and related phase angle associated and the internal fault can be easily distinguished from that perspective.

(Refer Slide Time: 36:14)



So, with this line differential protection is a very reliable approach in unit protection perspective. It requires dedicated communication for that perspective. We also see, the line differential protection can be extended with overhead line including transformer with tapped lines, multiple tapped lines also can be accomplished for the line differential perspective. We also see how phase compression approach can be applied with communication system arrangement for the line protections. But, this line differential relays also have their own limitation that is costly compared to distance relay schemes because of the communication and so. In case of communication fails, the method has no answer, it will not work at all unless the other end current information is there. Required synchronization of phasors for the EHV long lines either GPS or the newer technology or so. Differential relay do not provide any backup, it cannot say fault in other section of the line that is one of the important disadvantage of this one. Whereas in case of distance relay, even with the overcurrent relay, we have backup protection arrangement.

Distance relays have various backup schemes including zone 3 and no extra cost for this, so it uses only the local information and that. So, those are the limitation of line differential. But with today's reliable communication facility using the fibre optic or so, current differential relay application becomes increasing more in numbers. In addition, with the communication facility available, combining other relay principle like directional comparison including a distance relay applications during communication failure, we can integrate number of principles in same relay module and make corresponding decision process more reliable. They complement these principles, because they complement each other. Therefore, the accuracy of the precision or the reliability of the protection schemes becomes more enhanced. Thank you.