Digital Protection of Power System
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Lecture:30
Digital Distance Relaying Scheme for transmission Line-I

Hello friends. So, in this lecture, we will discuss about the digital distance relaying scheme used for the protection of transmission line. So, let us see first what is distance protection?

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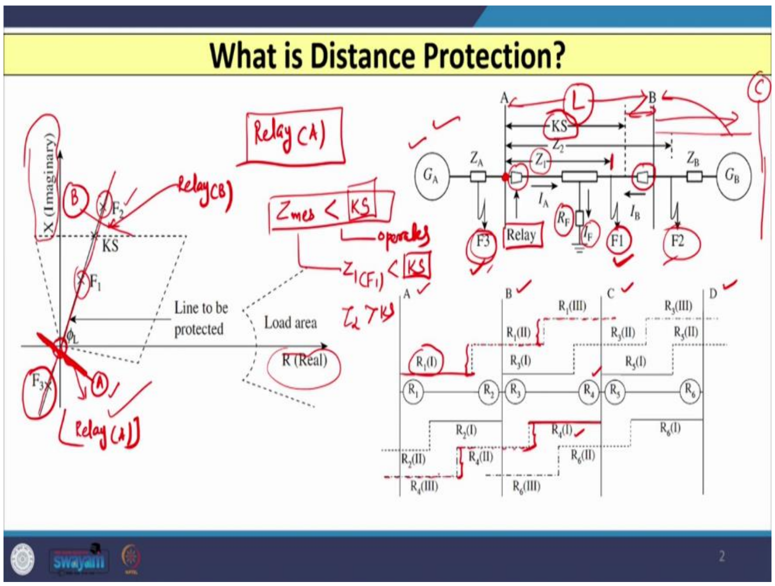

To understand this, the concept of distance protection, let us consider the single line diagram as shown here in which one generator at substation A is connected and another generator at substation B that is connected and between A and B transmission line is there and length of the transmission line is let us say L is the length of the transmission line. Now, we have a relay located at bus A or substation A and we also have a relay located at substation B and this relay that is shown here (as shown in above slide).

Now, if I consider a fault, let us say at the middle of this line with fault resistance R_F then the two currents, one is available from the substation A and another is fed from the substation B that will be there and your fault current I_F that is nothing but the addition of current available from substation A and current available from substation B.

So, if we consider three different cases of fault, let us say the one fault I am considering that is F_1

The another fault I am considering that is say somewhere here F_2 that is beyond the bus B and another fault I am considering that is at F_3 that is the beyond the bus A. Now, if I consider the relay located at substation A that is this relay. So, I am calling as a relay located at bus A or substation A.

So, if I consider the performance of this relay, then we know that normally the first zone of the distance relay that is set at 80 percent of the line length that is L, so the first zone of this relay that will be up to here and this will consider as a set value of the relay. So, set value of this first zone that is KS. So, if the measured value of impedance is less than the KS, then relay operates otherwise relay blocks. So, this is the operating principle of the distance relay.

Normally, each distance relay has three zones, the first zone cover 80 percent of the line length and First zone is the instantaneous operation zone, the second zone is a time delayed zone which covers the remaining 20 percent this one and it will also go the adjacent line 50 percent. And again the third zone is also a time delayed zone and that will cover the end of the next to next substation.

So, if I consider the three faults as shown here (as shown in above slide) F_1, F_2, F_3 and the setting or the set value of impedance is KS, then if the measured impedance is less than the set value of impedance then relay operates otherwise relay blocks and when fault occurs at F_1. So, this measure value of impedance is Z_1 in case of the occurrence of fault at $F_1$and this Z_1 is less than your value of set value that is KS, so relay operates.

So, normally distance relay has different characteristics let us say we have impedance characteristic, we have more characteristic, we have quadrilateral characteristic, it has let us say lenticular characteristic, elliptical characteristic and so on. So, the most widely used characteristic in distance relay that is known as quadrilateral characteristic. And this characteristic is shown here. All the characteristics of the distance relay are shown on RX plain with on x axis we will consider the R or the real part and on y axis we consider the X or the imaginary part.

So, if I consider the line to be protected is shown by this hard line (as shown in above side), and this is the origin. So, this point is the place where your relay A is located. So, your relay A is located at this point and your relay B is located at the opposite end. So, let us say your relay is B is located somewhere here at this point (as shown in above slide). So, you have a relay located at

B point.

So, we have two relays, relay A and relay B. So, this is your we can say the bus A and this is your bus B. So, here you can see that if I consider the fault at F_1, then the measured value of impedance that is Z_1, is less than KS. So, any fault which is going to occur below this KS relay operates in its first zone and the instantaneous operation is achieved.

For a fault at F_2 the measured value of impedance is Z_2 and Z_2 is not less than KS it is greater than KS. So, the F_2 fault line that comes here, and you can see that distance relay does not operate in its first zone, though F_2 fault comes under the second zone, but as second zone is a time delayed zone. So it will wait for the operation of another primary relay and it provides backup.

Similarly, if I consider the fault at F_3 for the relay located at A, that is at this end, then the F_3 fault falls on the reverse side of this. So, it will be in the third quadrant and hence a relay is not able to sense this fault, because it is in reverse direction. So, relay does not operate. So relay will operate only and only in its first zone only and only when the measured value of impedance is less than the set value of impedance.

Now, as I told you most of the distance relays, they have three zone operating characteristics. So, for several buses, if I add another line here between bus B and C and again another line between C and D as shown here (as shown in above slide), then you can see that we can have the three zone characteristic of relay located at bus A.

So, let us say that relay is R_1. So, this is the first zone of relay R_1, which is denoted by R_1(I). So, one in Roman letters indicates the first zone. Then we have a time delay that is of this and then again we have the second zone reach that will go up to the 50 percent of the adjacent line. Again we have another time delay. And then third zone we will go beyond this substation C. So, this is the three zone characteristic of distance relay located at substation A, indicated by R_1.

Similarly, if relays located and let us say at the substation C here and if we call it that relays as R_4, then this R_4 has the first zone that is 80 percent of this line length, that is R_4(I), again you have a time delay, and then again you have the second zone of R_4(II) and again you have a time delay and then the third zone of R_4(III). So, this is how the three step distance characteristic of distance relay looks like.

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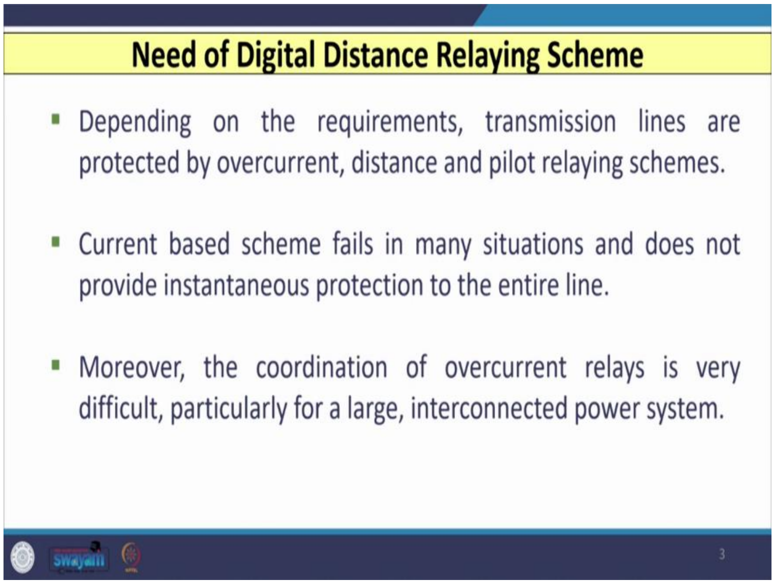

Now, let us see what is the need of digital distance relaying scheme? So, we know that depending upon the requirements, transmission lines are usually protected by either overcurrent relays, distance relays or pilot relays. Current base relays or the protection based on the overcurrent relays, that fails in many situations and that overcurrent relay does not provide instantaneous operation throughout the entire length.

So, if I have a overcurrent relay located for the protection of the long EHV and UHV lines, then this relay is widely suffered with the problem known as transient overreach. And hence in some several other situations also, this relay does not provide instantaneous operation for a fault occurring throughout the line length.

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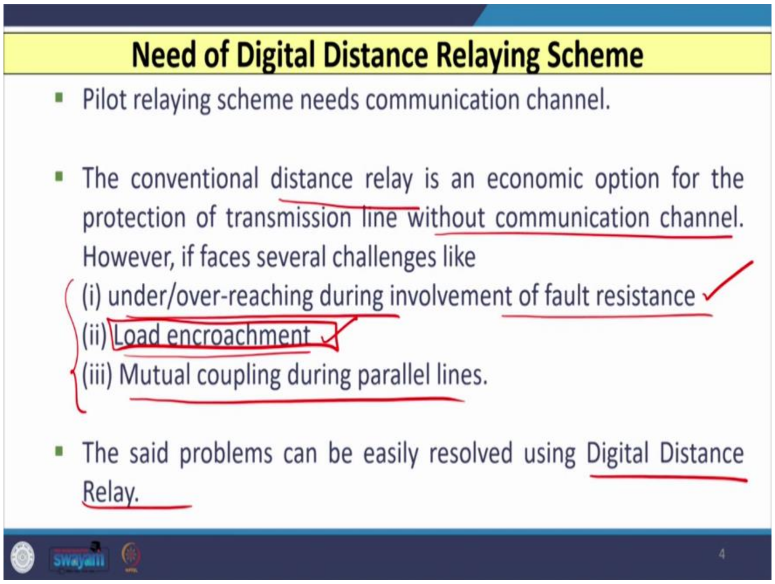

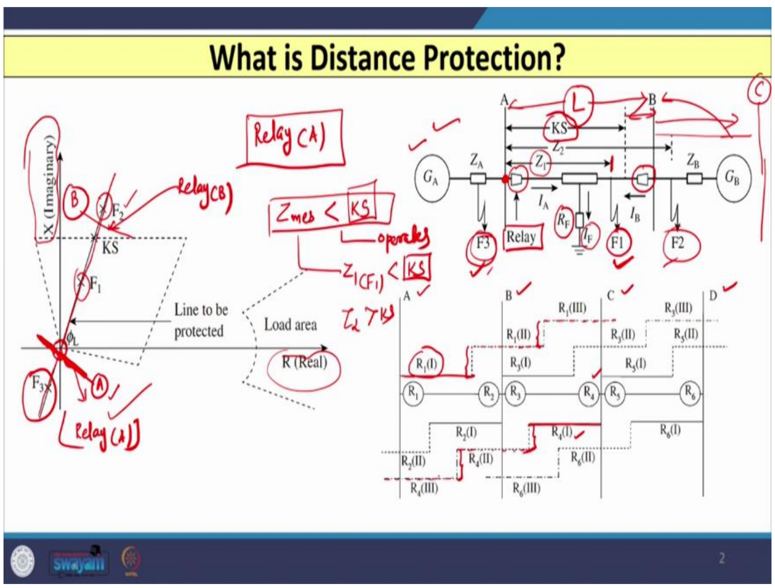

Moreover, coordination of overcurrent relays is very difficult for large interconnected system. So, that is why overcurrent relays for the protection of the long EHV and UHV lines as a primary relays that is not used. So, the other option is the either we can go for distance relay or we can go for pilot relaying schemes, pilot relaying schemes need communication channel and hence it is very costly. So, the only option that is known as the utilization of distance relay. It is very economic and we can have the protection have long EHV and UHV lines without utilizing communication channel.

However, if we use distance relay for the protection of long extra high voltage and ultra high voltage transmission lines, then this relay faces several challenges. And these challenges are maybe under or overreaching during involvement of fault resistance. So, whenever a fault occurs, I can show here we have considered the fault resistance that is RF. So, if we consider considerable value of fault resistance, and whenever single line to ground fault occurs, the impact of fault resistance is very important.

Because, in case of single line to ground fault, the tower resistance plays an important role, then you have ground resistance, arc resistance all these if you count then the effective value of fault resistance that is on the order of let us say 50 or 100 ohms. So, when we consider the impact of fault resistance, then in that case, you are relay may under reach or overreach depending upon the conditions. So, this is one of the major issues faced by the conventional distance relay used for the protection of EHV and UHV lines.

The second issue faced by the conventional distance relay is the Load encroachment. So, wherever there is a change in power flow, maybe because of the tripping of adjacent line or maybe switching off line or switching of generators, maybe because of fault in all such situations, the locus of the impedance may enter the third zone of the distance relay and distance relay may mal operate. So, this is also another major or severe issue or challenges faced by the conventional distance relay.

The third issue is the issue of mutual coupling during parallel or double circuit lines. So, when we have a distance relay used for the protection of double circuit lines, then because of the zero sequence mutual coupling impedance, which is almost 50 to 70 percent of the zero sequence impedance of the line, the relay may under reach or overreach depending upon some factor which is known as alpha factor.

So, if we wish to resolve this issues means this three issues or maybe several other issues, then the only option is we can go for digital distance relay, because this digital distance relay has several characteristic like the elliptical, lenticular, polygon, quadrilateral and so on, even it can also accommodate the fault resistance value also. So, the impact of fault resistance, that can be easily resolved.

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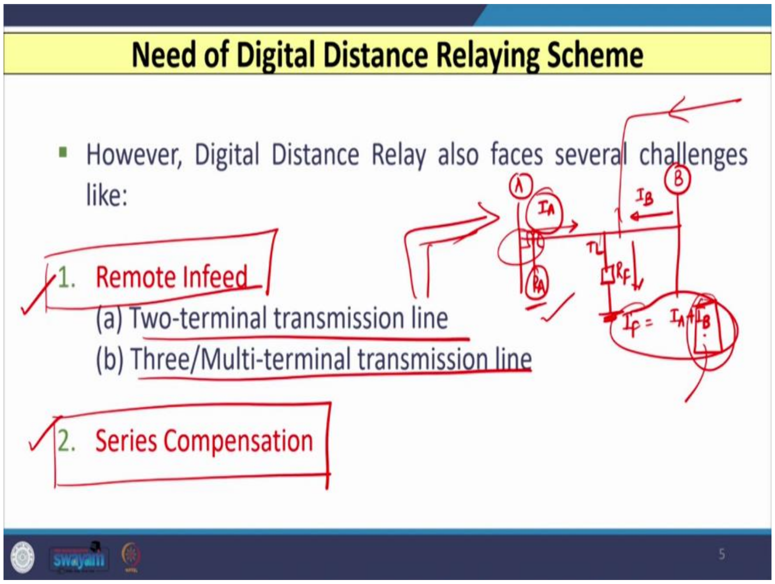

However, if we use digital distance relay and which is used by most of the utilities, then this relay also faces several challenges. Like the first challenge is the remote infeed. So, when you have bus and a line connected between the another bus, this is my transmission line. And if fault is going to occur at the middle of the line with or without value of R_F, then the fault current fed by this remote bus, that is nothing but your I_F that will be combination of the two currents, that is the local current I_A and the remote current I_B. So, the current which is their present in the fault current, that is the remote end current which is known as remote infeed.

So, this can be if I have another line here connected then another current will also be there. This currents I_B that is not measured by the relay located at substation A. So, substation A if I installed the distance relay distance relay can measure or use only the local current and local voltages. So, whatever impedance is calculated by this conventional relay, as it has not taken into account the value of remote infeed or remote current I_B. So, then this impedance measured by the distance relay R_A that is erroneous.

So, remote infeed is really a serious issue that is faced by the digital distance relay and remote infeed is mainly because of the two terminal transmission lines as I have indicated here and maybe we have three or multi terminal transmission lines. So, in both cases remote infeed effect is already observed and digital distance relay may mal operate in this situation.

The second problem that is faced by the digital distance relay is the series compensation. So, we know that when we have a transmission line, the transmission line can be uncompensated line or it can be series or shunt compensated line. So, when we have uncompensated line conventional distance relay or digital distance relay gives accurate result there is no issue.

However, when we have series compensated line, then the impact of series capacitor and metal oxide varistor which is nonlinear in nature that is going to affect the performance of the digital distance relay. So, in this lecture, we will consider these two issues that is faced by digital distance relay. So, let us first consider the issue of remote infeed faced by digital distance relay.

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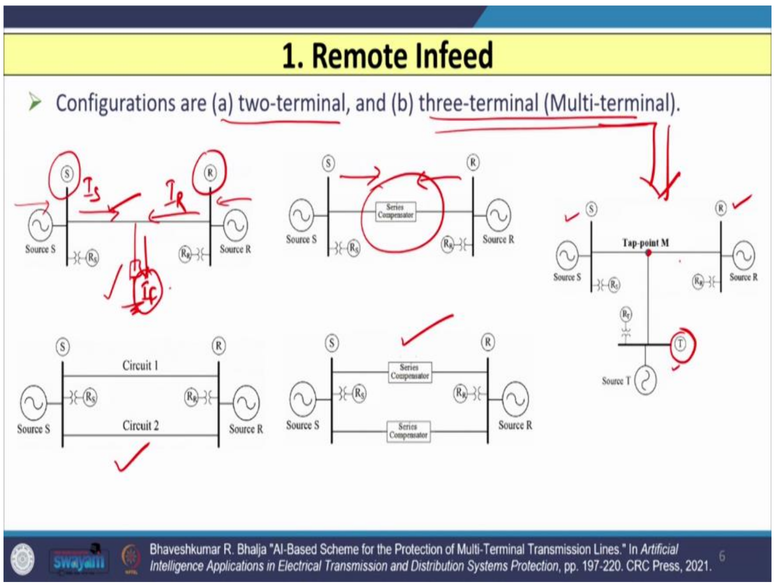

So, let us see what is remote infeed? So, when I consider the remote infeed situation or condition, we have to consider the two configurations of the transmission lines, the first configuration is the two terminal transmission lines. So, two terminal means we have the transmission lines connected from both the buses that is sending end, receiving end. So, we have the source at the receiving end as well as we have the source at sending end.

So, any fault occurs here on this line then in that case the current that is fed from both the end sending end as well as receiving end. So, here you have the fault current and you have the current I_S and you have the current I_R from the remote side, both the currents will be there, which is going to feed to the fault current. This is uncompensated transmission line, we do have a two terminal transmission line configuration when we have a series compensated line. So, in that case also two currents are available.

The another type for example or the configuration is we have double circuit line. So, again fed from both the end and we have series compensated double circuit lines configuration and the second type of configuration we have that is three terminal or multi terminal transmission lines.

So, here I have shown (as shown in above slide) three terminal transmission line configuration, where we have a tap point at M and I have taken another tap and that is connected to the terminal T. So, we have a source at terminal S we have another source at Terminal R and we have another source at terminal T. So, whenever a fault occurs anywhere the three source they are going to feed the fault current. So, these two configurations we have to study when we are dealing with remote infeed condition.

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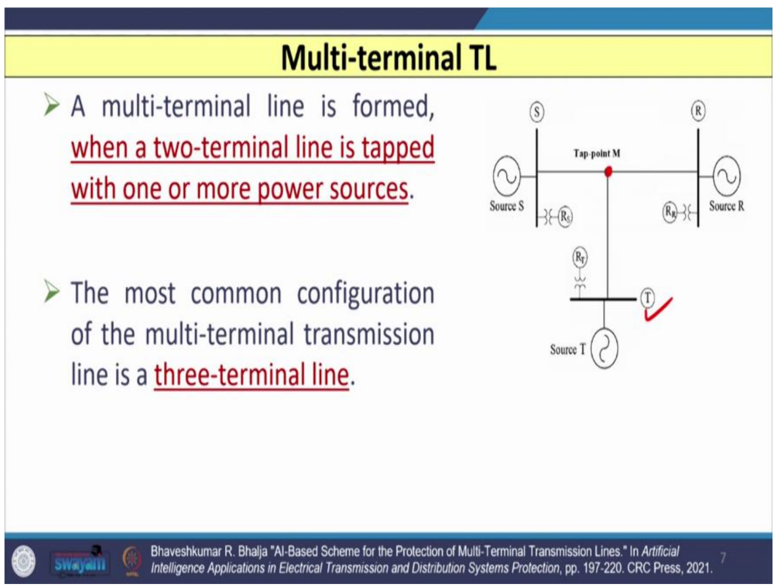

Now, let us consider what is multi terminal or three terminal transmission line? So, a multi terminal line is formed, whenever a two terminal transmission line is tapped or for when we take the tapping from the two terminal transmission line with one or more power sources, let us say we have a tapping tap point M and we have taken one tap and that is connected with source T at substation T. So that is known as multi terminal line.

And the most common configuration for multi terminal transmission line is the three terminal transmission line. So, our discussion will be again restricted to the three terminal transmission line.

However, it can be easily extended to multi terminal or n terminal transmission lines.

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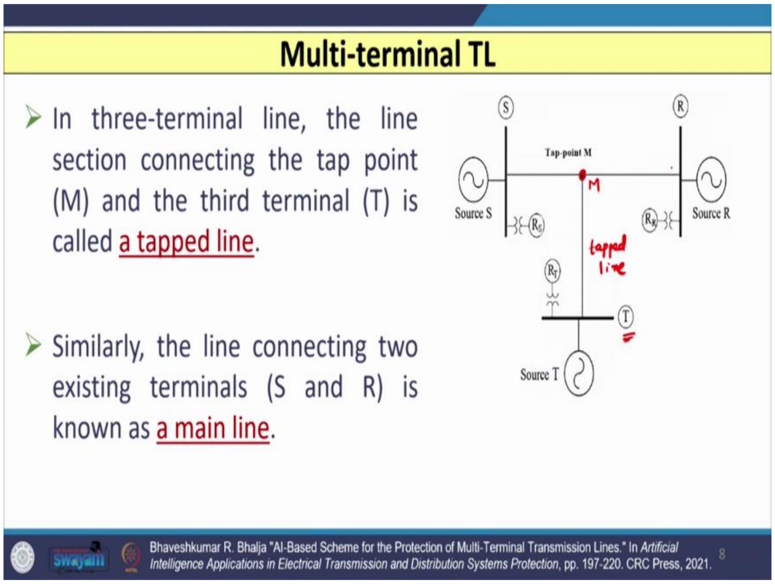

Now, if I consider the three-terminal transmission line, then the line section connecting to the tap point we have a tap point that is M to the third terminal that is substation T that is known as the tap line. So, this is known as the tapped line, because we have taken tappings from the conventional two terminal line. Similarly, the other two sections that is connected between S and M and between M and R this R is nothing but our main line.

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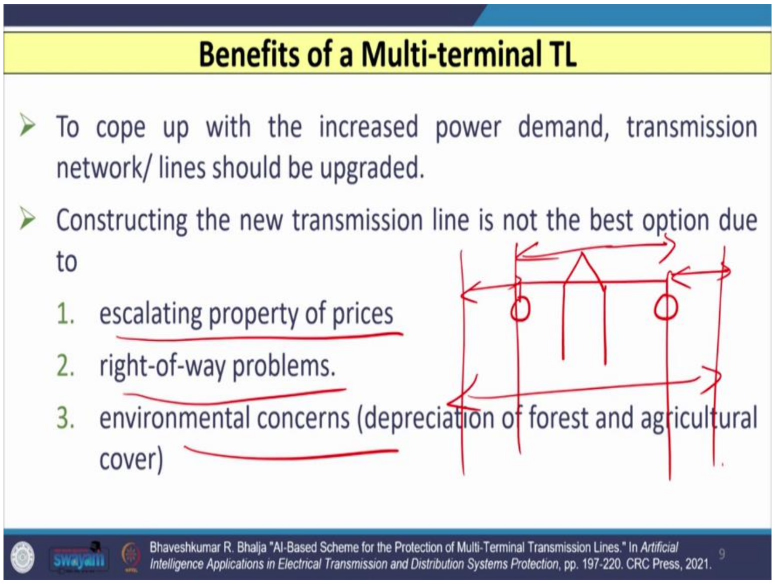

Now, let us see what are the benefits of multi terminal transmission lines? So we know that in order to cope up the increased power demand transmission networks should be always upgraded. So, constructing a new transmission line is not the best option because of several reasons. And there are mainly three reasons.

The first the prices are very high for constructing the new line. The second is the right of way problems. So, if I have a tower like this, and we have a cross arm like this, and we have a conductor on both the sides, then you know that this is your wire area and maybe you have some other area, which you need to left so this much of space or right of way that is required for every transmission tower and if your transmission tower is passing through the forest or maybe some agriculture land, then this much of space that is has no use, this is for one tower, same concept is applicable for all the towers.

The third is the environment concerns, because of the depreciation of the forest and agriculture cover. So, construction of new transmission line, that is not the best option.

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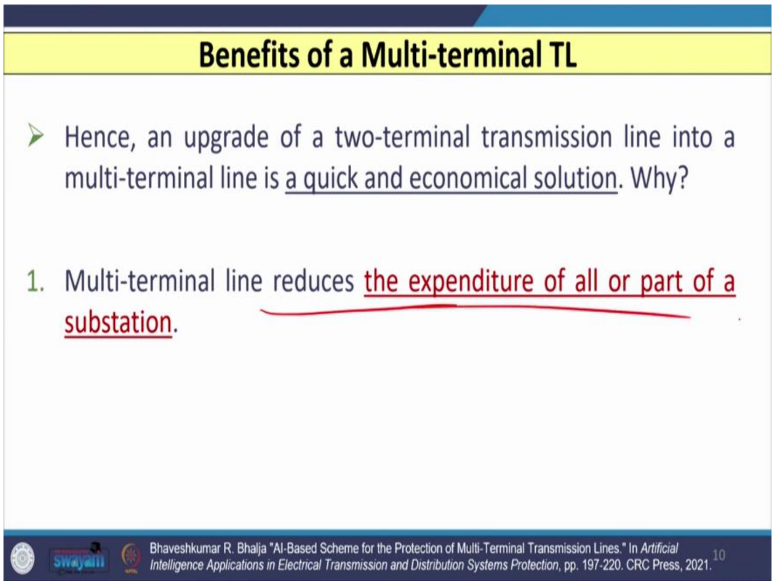

Hence, we need to upgrade the two transmission line by taking a tap from the conventional two terminal line, so that it becomes three terminal transmission line and this is the quick and economic option. Why? The reason is if I take the tappings from the conventional two terminal transmission line, and if it becomes multi terminal or three terminal lines, then the expenditure of all part or part of the substation that can be reduced.

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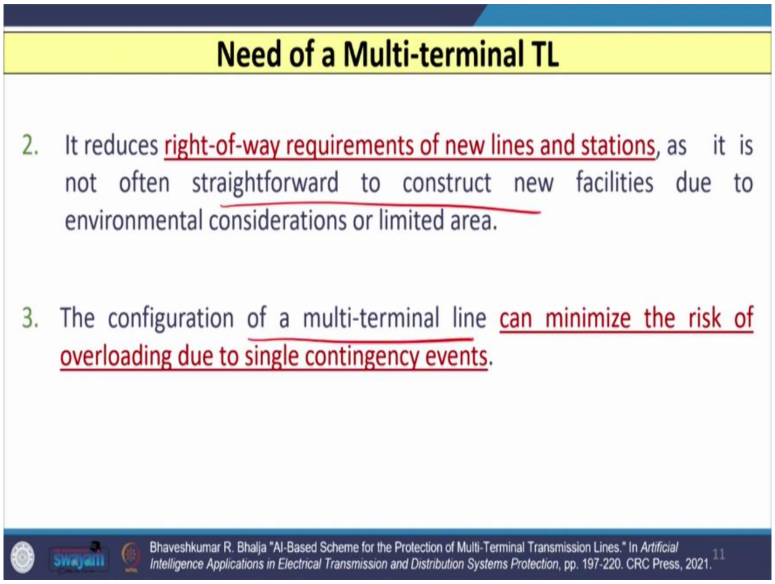

The second is if I have multi terminal or three terminal line, it reduces the right of way requirements for new lines and stations as it is not often straightforward to construct new facilities due to environmental considerations or limited area. So, it is not possible to construct a new transmission line which is very difficult, because of the three reasons which I have mentioned earlier. So, the only option is the multi terminal line or three terminal line.

And the third another very important point is if I go for multi terminal line, then it can minimize the risk of overloading due to single contingency events. So, if I construct two transmission lines, then the chances of occurrence of fault on two lines that is higher compared to why I have only single line which I am converting into multi terminal or three terminal transmission lines.

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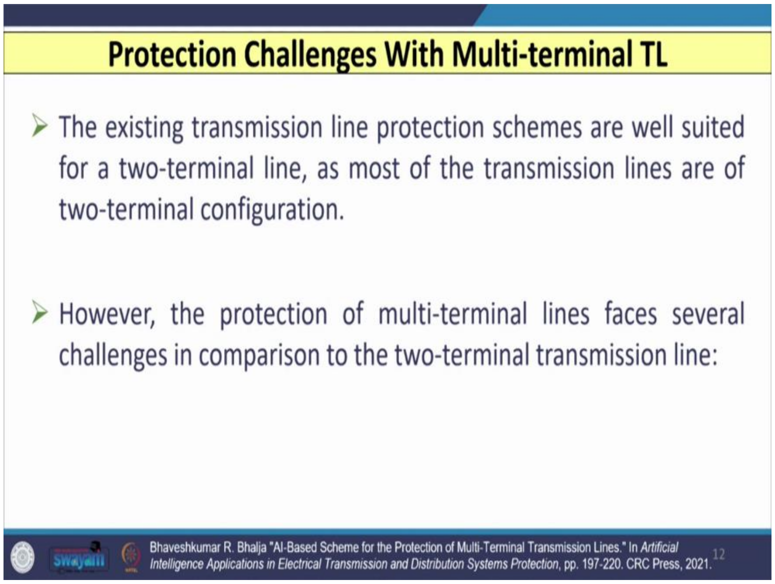

Now, let us see what are the protection challenges with multi terminal transmission lines? So, the existing transmission line protection schemes are well suited for two terminal transmission line, but when we are applied to multi terminal transmission line, then they face several challenges.

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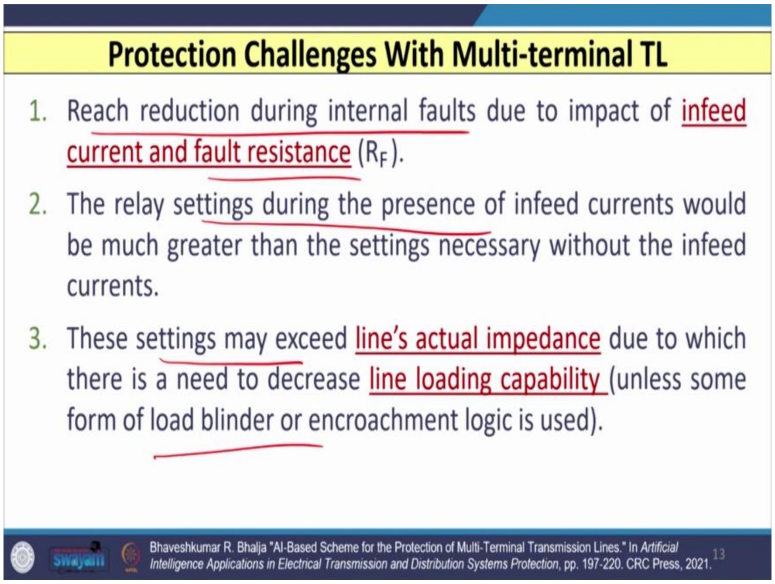

Let us see what are those challenges? The first challenge is the reduction in reach in case of internal fault because of the impact of remote infeed and fault resistance R_F. The second is the relay settings during the presence of infeed current that would be much greater than the settings which is required when infeed currents are not present. So, when there is no remote infeed whatever settings are there and when there is a infeed is present the settings are there both are entirely different.

The settings sometimes may exceeds lines actual impedance, because of which there is a need to decrease the line loading capability unless you have used maybe some encroachment logic or maybe you have used some blinder logic, otherwise you have to decrease the line loading capability. So, that there should not be any mal operation of the conventional distance relay when it is used for the protection of multi terminal or three terminal transmission lines.

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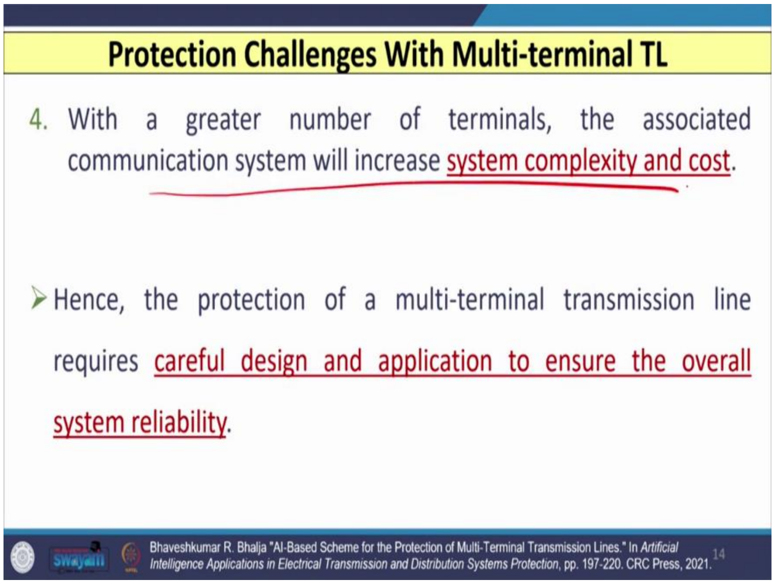

With a greater number of terminals, the associated communication system will increase system complexity and cost. Hence, protection of multi terminal transmission line whenever we carry out it requires careful design and application to ensure overall system reliability.

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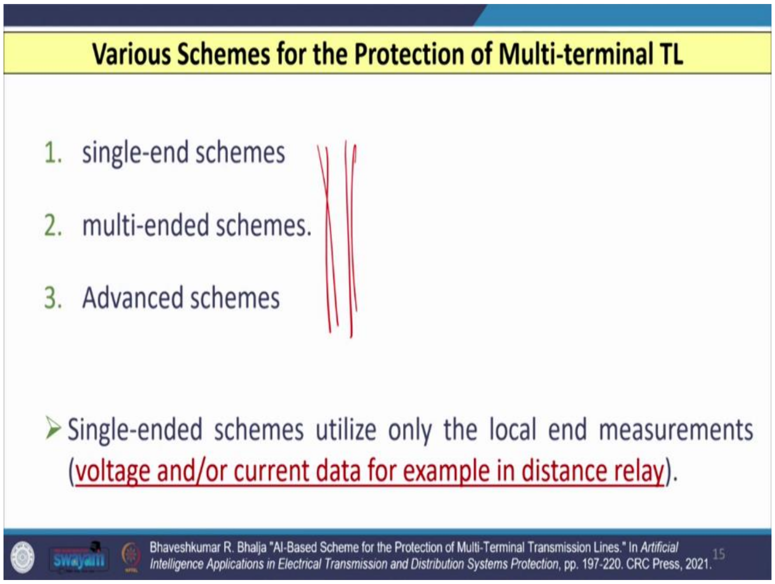

So, let us see what are the various schemes that is used for the protection of multi terminal transmission lines. So, normally the people use the three schemes for the protection of multi terminal transmission lines. The first one is the single end schemes as the name suggests, it will take only measurement from sending end or local end. The second is the multi ended schemes can take the measurements from several buses.

And the third is the advanced schemes that is based on maybe some recent techniques or maybe pattern recognition or maybe traveling wave like that. So, let us consider each of the scheme one by one. So, if I consider a single end scheme as the name suggests, it utilizes only local measurements. So, maybe voltage or maybe current or both. That is used as that is done by the conventional distance relay.

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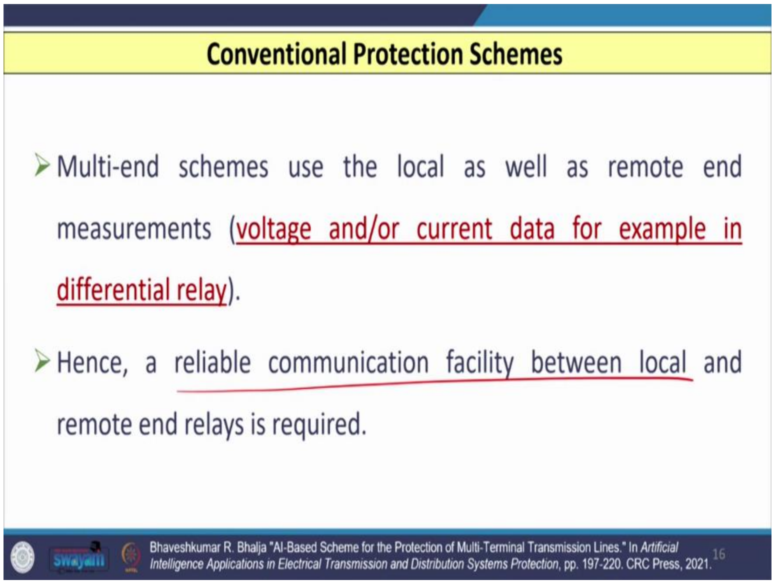

Multi ended schemes, that uses measurements from remote as well as some other buses. So, voltage or maybe current or maybe both the quantities. Then let us say example is differential relay is the best example used for transmission line. Hence, a reliable communication facility between local and remote end is required if you use multi ended schemes, because you need a measurement from the remote or maybe several other remote buses also.

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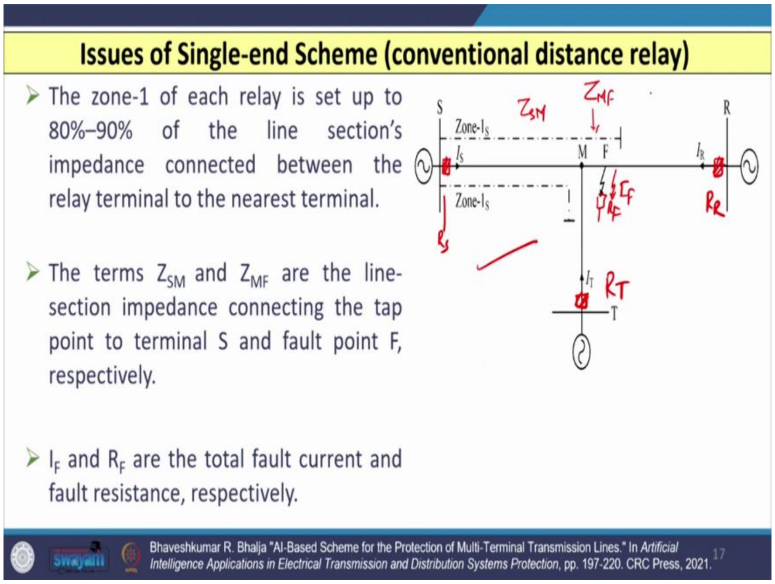

Now, let us see what are the issues of single ended scheme or maybe conventional distance relay, when it is applied for the protection of multi terminal or three terminal transmission lines. So, to understand this let us consider a one single line (as shown in above slide) diagram of multi terminal or three terminal line, the three relays are connected here, one is at this end, another is at this end and another is at this end.

And first zones setting of all the three relays located at let us say this is R_S, this is R_R and this is R_T, the first zones setting of all the three relays that is 80 to 90 percent of the line length, If is the fault current let us say you have the fault current If with some value of R_F and the other impedances between let us say the impedance between S and M that is Z_{SM} impedance between M and F that is Z_{MF} and so on, so, you can consider this.

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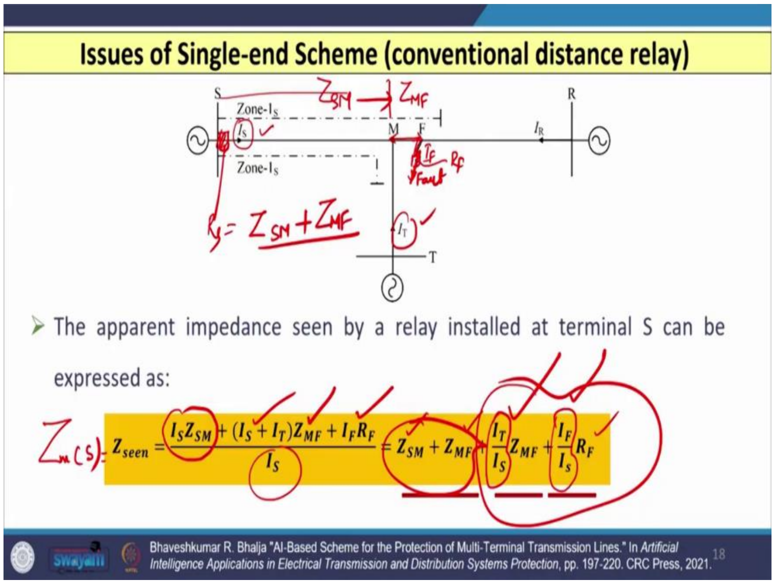

Now, if I consider what is the apparent impedance seen by the relay installed at terminal S, then it can be given by the measured value of impedance by relay, let us say at substation S or terminal S that is nothing but the voltage drop between S and M.

$$Z_{seen} = \frac{I_S Z_{SM} + (I_S + I_T) Z_{MF} + I_F R_F}{I_S} = Z_{SM} + Z_{MF} + \frac{I_T}{I_S} Z_{MF} + \frac{I_F}{I_s} R_F$$

So, here if fault is going to occur here, then in this section, the current that is flow that is because of I_F and that is because of I_T.

So, actually, if fault is going to occur at this point, then distance relay located at S, Let us say R_S, it has to measure the impedance that is Z_{SM} plus Z_{MF} only this. So, first two terms. However, because of this remote infeed that is this term, and because of the other term that is impact of R_F that is this term, this additional two terms are involved and hence the apparent impedance seen by the relay is different than the actual or true value of impedance.

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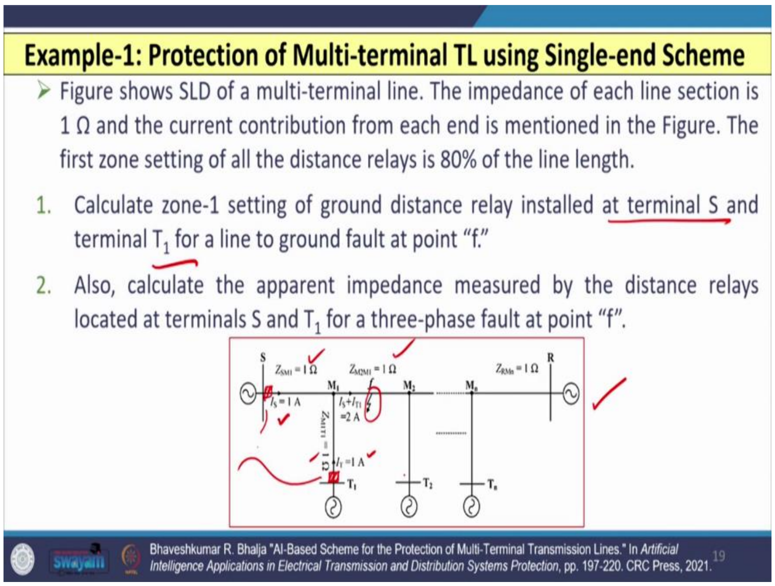

Let us see one example. Here you can see (as shown in above slide) I have shown the multi terminal transmission lines and the first zone of the relay is set to 80 percent the impedance of each line section is shown here that is 1 Ω you can see here and the current values are also mentioned, I_S is 1 A, I_T is 1 A that is also mentioned here. And in this case, we need to calculate the zone 1 setting of ground distance relay installed at terminal S and terminal T_1 for a line to ground fault that is going to occur at this point.

So, if fault occurs here, what is the zone one setting of relay located here and relay located here at T_1 terminal. And second, we need to also calculate the apparent impedance measured by the distance relay at same terminal S and T_1 both for a three phase fault at F, in part A single line to ground fault occurs and in part B three phase fault occurs.

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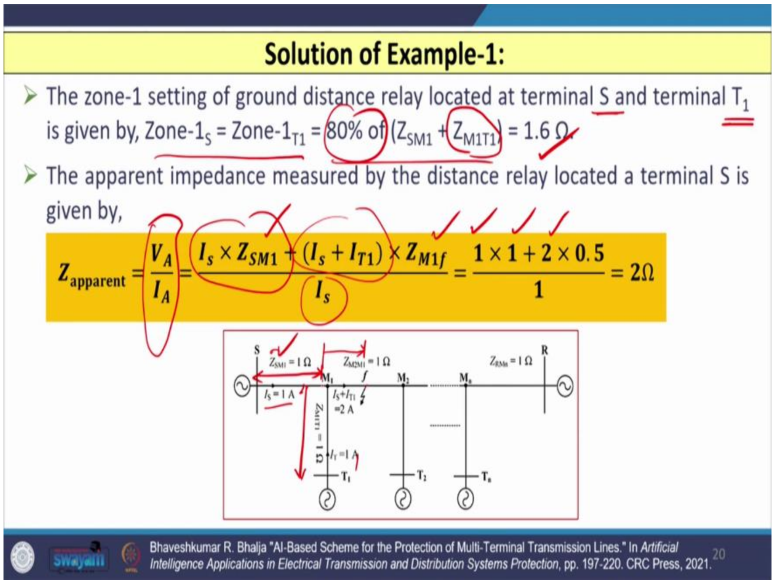

So, the zone 1 setting if I just calculate for the relay located at terminal S and terminal T_1, then that is nothing but the Zone-1_S = Zone-1_{T1} = 80% of (Z_{SM1} + Z_{M1T1}) = 1.6 Ω.

So, the apparent impedance measured by the distance relay located at terminal S that is given by

$$\boldsymbol{Zapparent = \frac{V_A}{I_A} = \frac{I_s \times Z_{SM1} + (I_s + I_{T1}) \times Z_{M1f}}{I_s} = \frac{1 \times 1 + 2 \times 0.5}{1} = 2\Omega}$$

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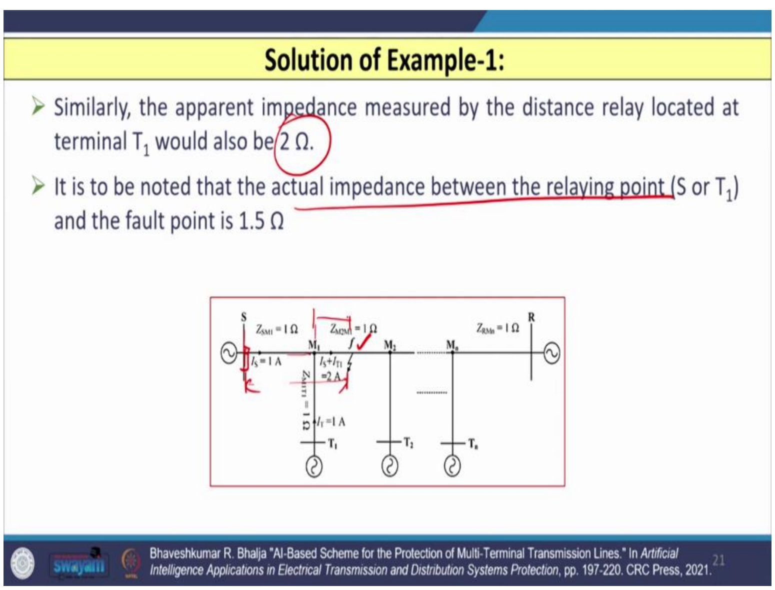

Similarly, you can calculate the apparent impedance measured by the distance relay located at terminal T_1 and that is also comes out to be 2 Ω. So, here you can just note that the actual impedance between the relaying point S or T_1 and the fault point here if I consider the relay here, the actual impedance between this relay and this point that is only 1.5 Ω, because this is 1 Ω and this is half 0.5 Ω, so relay has to measure only 1.5 Ω, but it is going to measure the value that is 2 Ω, because of the remote infeed phenomena.

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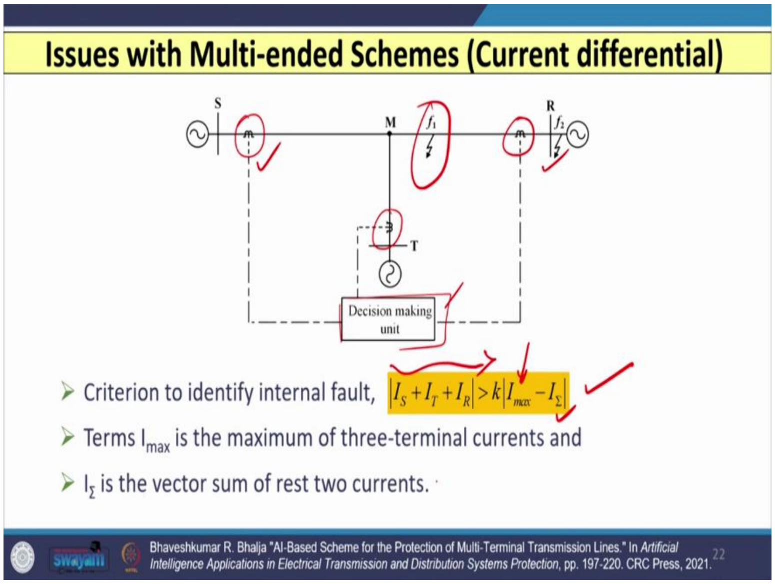

Now, let us see the second category of scheme multi ended schemes. So, the best example is the current differential. So, here (as shown in above slide) I have shown the three terminal line with a differential relay unit which is going to take the currents from the substation S substation R and substation T and all the three currents are available here.

And in case of any internal fault here at f_1, the decision will be taken based on this equation $|I_S + I_T + I_R| > k|I_{max} - I_\Sigma|$, if this is satisfied, then relay operates otherwise relay blocks.

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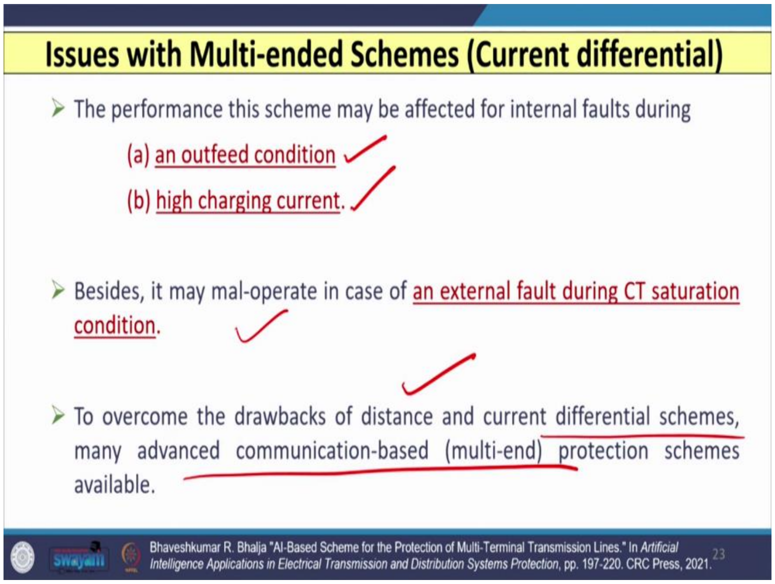

However, there are some issues faced by current differential scheme. Performance of this current differential relay, that is affected in case of internal fault particularly when there is an outfeed condition and when high charging currents are there. Moreover, in case of external fault with CT saturation, this relay may mal operate. So, if we wish to overcome this drawback of distance and current differential schemes that is single end and multi ended schemes, we have to go for some advanced techniques maybe based on communication or maybe with some other philosophy which we need to use.

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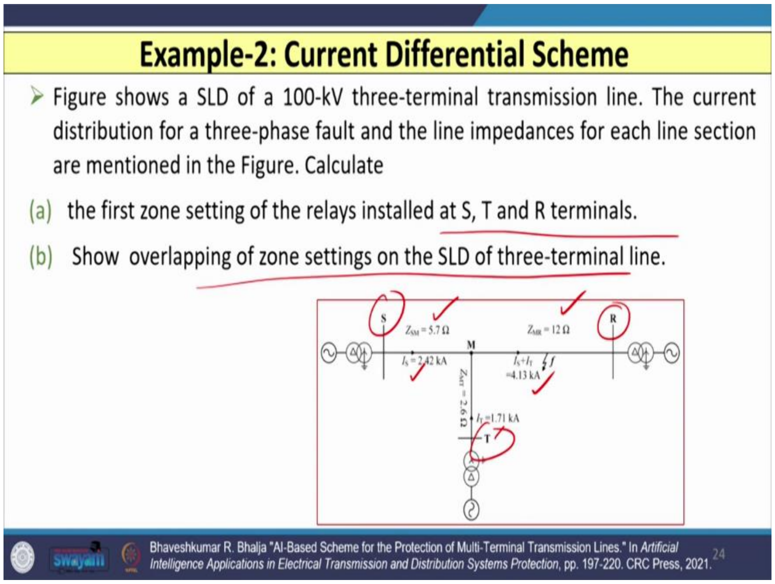

If I consider another example for current differential scheme, let us consider one single line diagram of three terminal transmission line that is 100 kV line and the current distribution and the impedances are shown here in the figure (as shown in above slide). And you can see we need to calculate the first zone setting of the relay installed at each end that is substation, S substation R and substation T. And in second case, we have to draw the overlapping zones on this diagram itself showing that this for three terminal transmission line for all the relays located at S, R and T.

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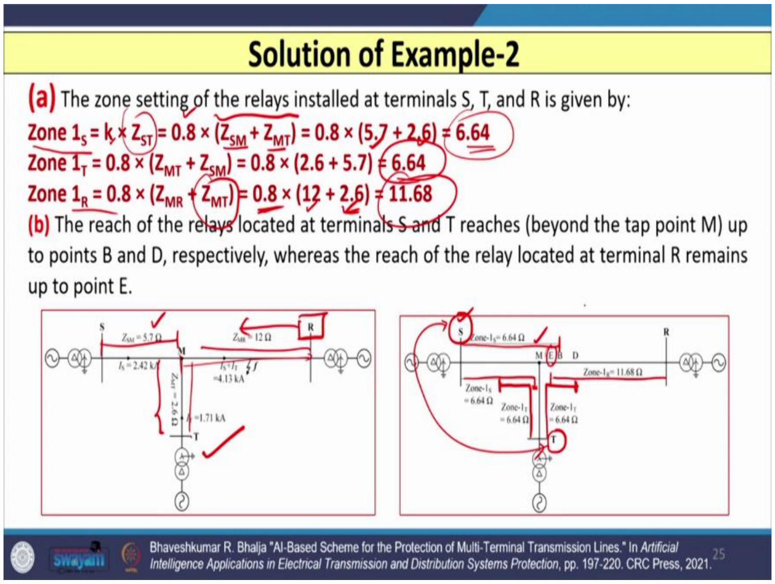

So, if I calculate the first part that is the zone settings of the relay located at S, T and R, then the relay located at S that is nothing but the k times the Z_{ST}. So, here you can see K is my 80 percent is the I am assuming that the reach of first zone is 80 percent so k is 0.8.

$$\textbf{Zone } 1_S = k \times Z_{ST} = 0.8 \times (Z_{SM} + Z_{MT}) = 0.8 \times (5.7 + 2.6) = 6.64$$

Now here along with Z_{MR}, which is 12 Ω, the other option is either you can take Z_{MT} or you can take Z_{MS}, but here you have to take the Z_{MT} only that means that section which has the lowest value of impedance, so that I have considered and you will get 11.68.

$$\textbf{Zone } 1_R = 0.8 \times (Z_{MR} + Z_{MT}) = 0.8 \times (12 + 2.6) = 11.68$$

If you consider the another section Z_{SM} here, then this reach of relay located at r that may exceeds this reach that is 12 Ω. If I draw the overlapping zones, then you can see that the reach of the relay I have shown here. So, you can see zone 1 of relay located at S that is 6.64. So, that will go up to this point B. For this say main line and it may go up to let us say somewhere here this point for this empty sections.

Similarly, if I consider zone 1 of the relay located at this point, then it is zone 1 will go up to this point D that is 6.64 on mainline towards r and it reach may also go up to this point that is towards the source S, that is also 6.64. And if I consider the zone 1 of relay R, then you can see its reach will come up to point E from the bus R which is 11.68. So, the reach of relays located at S and T both this you can see, that will go beyond the tap point M, however the reach of the relay located at R that will remain upto point E, It will not go beyond tap point M.

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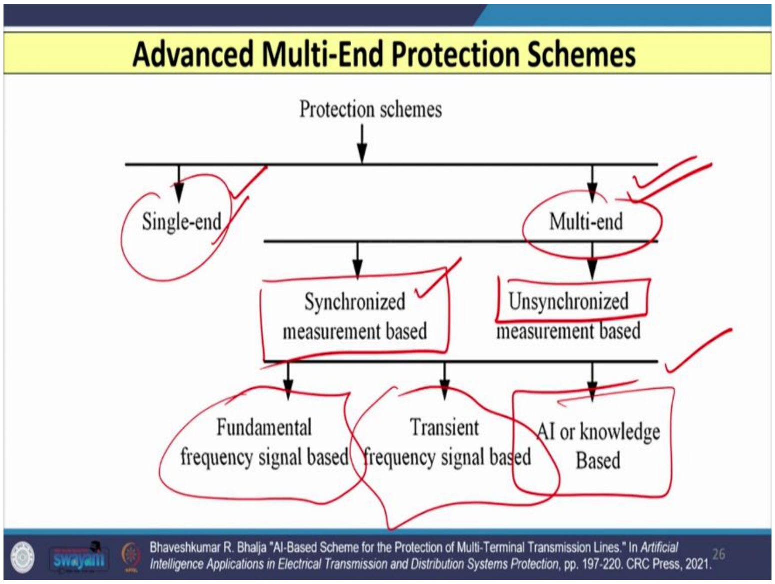

And the third category of the protection schemes which we are going to use, two we have already discussed single end and multi end. So, the third category of this that is advance schemes and this schemes are classified as the scheme based on synchronized measurement and the another scheme based on unsynchronized measurement. So, normally unsynchronized measurement does not require any synchronization or any data from the remote end.

However, nowadays only synchronized measurement based schemes are widely used. And this schemes are based on either, let us say fundamental frequency signal based or maybe transient signal based or maybe pattern recognition or traveling wave based scheme such type of schemes are also available.

So, in this lecture, we started our discussion with what is the distance relay, then we have discussed that what are the several issues or challenges faced by the conventional distance relay, then we have seen the importance of digital distance relay and then we discuss that digital distance relay also faces two issues one is remote infeed and another is the series compensation.

And we have discussed one of the important issues that is the remote infeed and to tackle these three different techniques are used, one is single ended another is multi ended and third one is some advanced schemes and all drawbacks of these two schemes single end and multi ended we have discussed with examples.

And the third scheme which are used nowadays, and this schemes are based on synchronized measurements based on Synchro phasers. So, we have a GPS using which we can take the synchronized measurement at different buses. So, this is widely used for the protection of multi terminal transmission lines. Thank you.