Power System Protection
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Lecture No. 46
Protection Challenges of Distribution Systems with Renewables

Welcome to NPTEL course on Power System Protection. We are continuing with the modules on Network Protection with Renewables.

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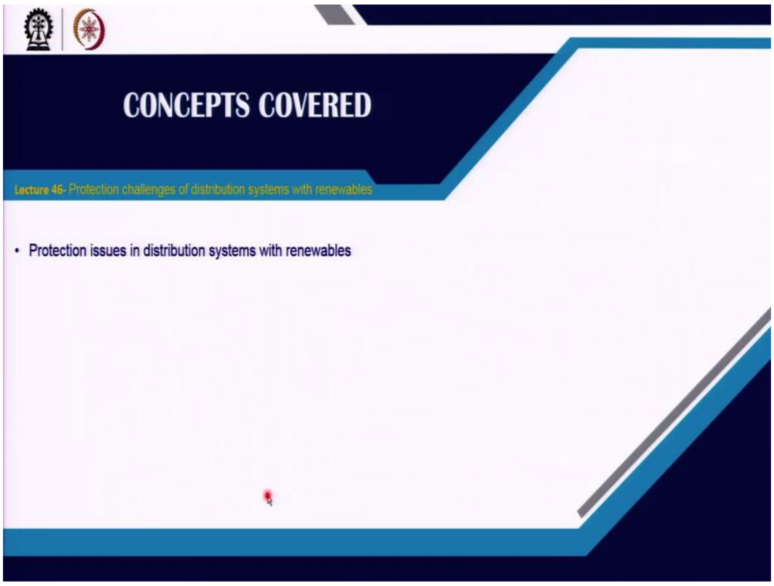

In this lecture, we will address the protection challenges specifically to distribution systems. In last lecture, we have seen that renewables in the form of photovoltaic, wind and others, they are being integrated to the network using inverters and transformer arrangements. And in that, such situations, they contribute current and voltage differently than the conventional synchronous machine-based sources. That makes the big difference in the fault characteristics of such distributed energy resources.

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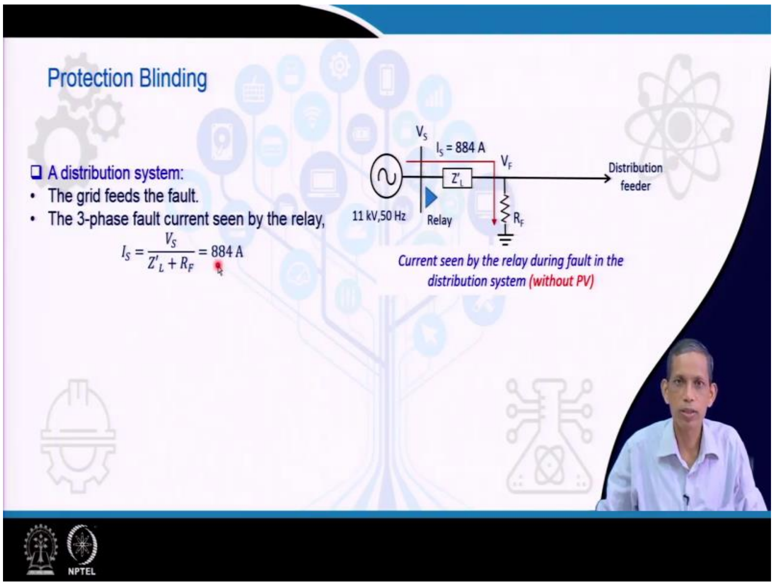

Let us come to some challenge, few challenges which we like to see in this lecture related to distribution system. First one on protection blinding. So, this is a distribution system 11 kV 50 Hz system and this feeder runs to meet the certain load. A fault happens to be there at point F here with certain resistance R_F. Let us, this is a 3-ϕ fault situation, so therefore, this relay will see settlement of current based on the associated fault impedance and the R_F. Typically, for 3-ϕ fault, R_F is much smaller. Now, we have considered here the source to be pretty strong, so as compared with these impedances, source impedance is much smaller. So, for this 3-ϕ fault case, the corresponding I_S becomes

$$I_S = \frac{V_S}{Z'_L + R_F} = 884 \text{ A}$$

So, let us say, for this case, the system simulation reveals 884 A.

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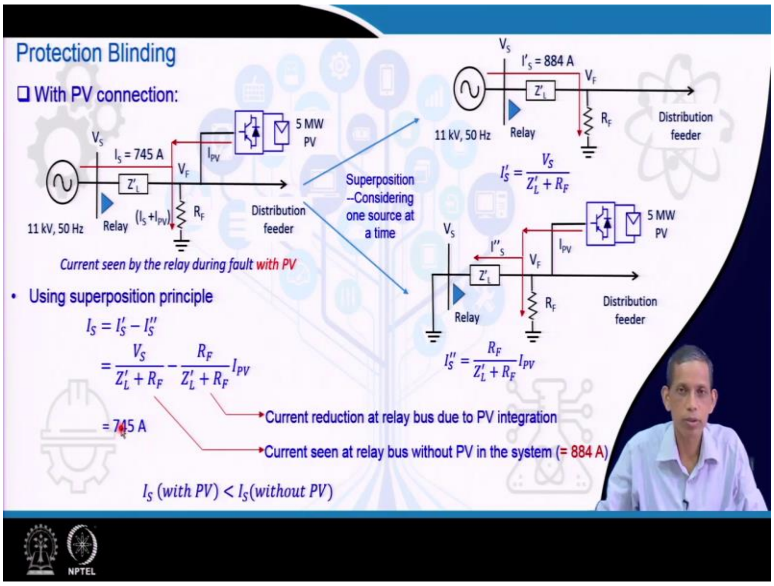

Now, we include in this system a PV connected just beyond the fault position. So, this PV, let us say capacity of 5 MW. Now for this fault, the grid provides as usual fault current, and source to the PV provides fault current. So, there are two currents contributed by the 2 sources. So, that means that to this fault, the total current will increase. So, that current is I_S from the grid site and I_{PV} from the 5 MW photovoltaic plant. Now, what happens, we will have to analyse. So, this can be analysed considering each source. So, superposition theorem we can apply and let us say, first, the, our conventional grid side. So, the grid side path, we have already analysed in the earlier slide. So, that becomes

$$I_S' = \frac{V_S}{Z_L' + R_F}$$

Now, the other part that the PV system, which happens to be a current source, so the current source in this case the current source remains open, so that path is not shown in this case. Now, this current source, I_{PV} will supply to this fault, and this side will be sorted here, considering the 11 kV source to be small impedance, negligible impedance. Therefore, the current component of the PV side outfeed to the relay bus becomes

$$I_S'' = -\frac{R_F}{Z_L' + R_F} I_{PV}$$

Now, considering the PV and grid side contribution separately this total current is flowing through this relay at the substation will be

$$I_S = \frac{V_S}{Z'_L + R_F} - \frac{R_F}{Z'_L + R_F} I_{PV}$$

That means this relay will see a less amount of current for the same fault position for same R_F, everything remaining same in the presence of PV as compared to without the presence of PV. So, that is found to be 745 A as compared to the 884 A when the system does not have the photovoltaic plant. Therefore, what do you see that this a factor of this with the contribution from the I_{PV}, when the PV is connected beyond the fault point in this arrangement, then there is an observation that the substation relay current decreases. So, that, we say that the I_S, the current seen by the relay with PV becomes less than without PV. Further, you can say that more the PV capacity, more will be current from the PV, I_{PV} will be more and more. And with more amount of I_{PV} these negative part becomes more. Therefore, the decrement in current becomes more and more.

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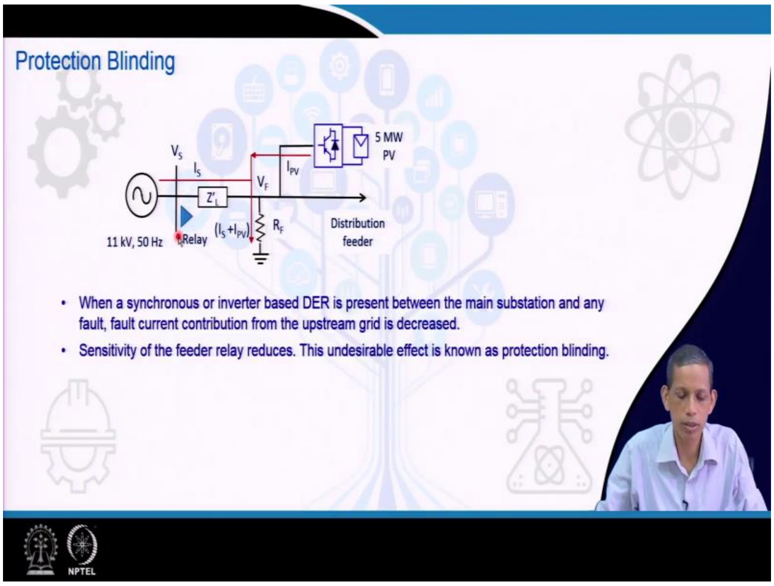

So, what we can say here that in case of smaller current in the IDMT curve, smaller current means the corresponding time taken will be more and more. When a synchronous or inverter based DER is present between the main substation and any fault as we discuss here, fault current contribution from the outstream grid is decreased, that is what, we say that the relay will now decrease the amount of current. Sensitivity of the relay decreases. This undesirable effect is called the blinding. And that is what delayed the decision process of this relay.

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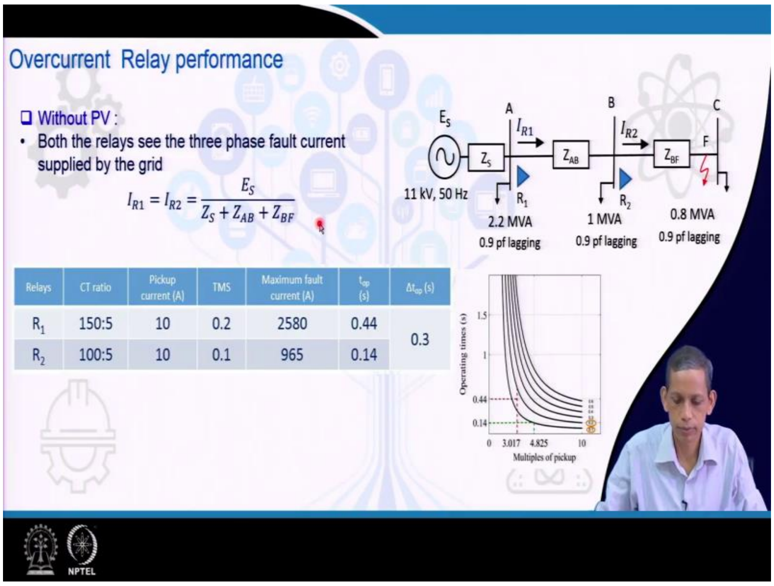

Furthermore, going into the distribution system issue with renewable issues. So, we will see how the existing overcurrent relay will perform in case of presence of any DER like PV or so. Now, let us have a system having 3 buses and we have the corresponding fault at F and we have 2 relays here R_1 and R_2. These R_1 and R_2 are being, having CT ratio 150: 5, 100: 5. Pickup current, let us say, both are having 10 A. We have learned this in the overcurrent relay principle coordination earlier in the lectures. The R_2 to the farthest relay, will have the smallest time multiplier setting.

So, that you can say, the TMS of 0.1 that belongs to this R_2, and let us say as per the setting, we have TMS point for the R_1 for this distribution system with having different loads and all these things clearly mentioned here. Now, we say for this fault the IR_1 and IR_2 will becomes to,

$$I_{R1} = I_{R2} = \frac{E_S}{Z_S + Z_{AB} + Z_{BF}}$$

Let us say, this is a 3-phase fault case.

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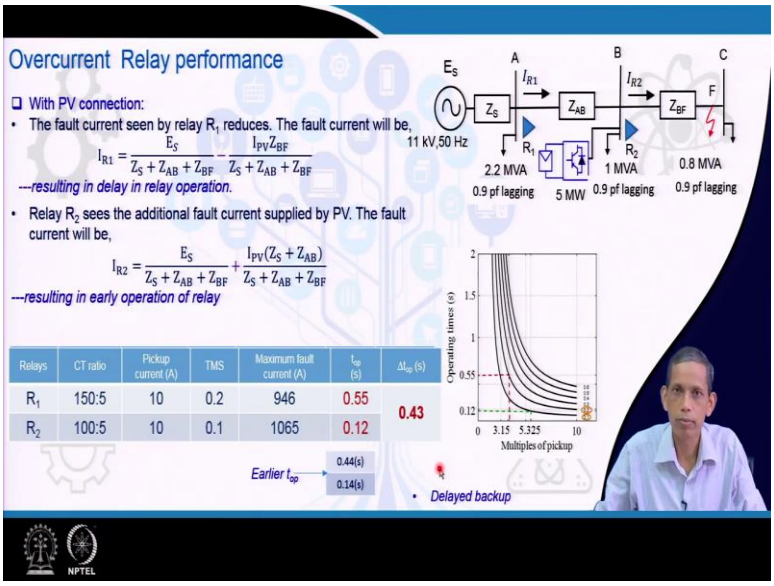

Now, what will happen, if a 5 MW PV is connected at bus B. Now for the same fault with PV connections, the fault current seen by relay R_1 decreases. We have already mentioned that with PV connected in case of here, the corresponding current seen by this R_1 will decreases, resulting in delay in relay operation upward this R_1. But for R_2 what happens, we see here, the amount of fault current for this fault will be contributed from this side, from this source and as well as this source. So, the amount of current seen by the relay increases. From these relations and result we had that the relay R_1 sees less amount of current and relay R_2 sees the larger amount of current. Therefore, the corresponding R_2 decision time decreases from 0.14 s to 0.12 s and R_1 decision time increases from 0.44 s to 0.55 s. Note that for this fault, R_2 is the primary relay and R_1 is the backup relay. What you observed that the backup relay decision is being delayed. So, the consequence of overcurrent relay is that it results in delayed backup situation.

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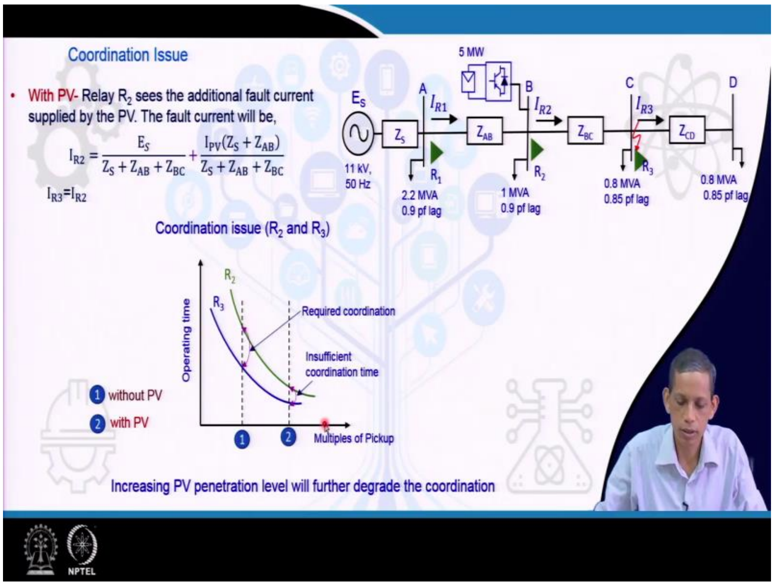

Next there may be issues on the coordination in the overcurrent relay operation. See, a system like this, we have multiple buses here in the distribution system and we will have coordination between relay R_2 and R_3, the last 2 relays in this system perspective with the PV connected at bus B. So, what happens as the coordination we have for the maximum fault current, what are R_3 sees, that is the basis for the coordination between R_3 and R_2, because R_2 will protect also line section CD as a backup, primary being the relay R_3. For this case, the corresponding current through relay R_2 will be

$$I_{R2} = \frac{E_S}{Z_S + Z_{AB} + Z_{BC}} + \frac{I_{PV}(Z_S + Z_{AB})}{Z_S + Z_{AB} + Z_{BC}}$$

Now, this current will be through these R_3 relay, so

$$I_{R3} = I_{R2}$$

Now, what will happen in this case that between R_2 and R_3? So we choose the lower curve for R_3 relay and the upper curve for relay R_2 in terms of the coordination business. So, earlier when PV was not there, then the coordination was being carried out at the, these positions. So we have a coordination here and this coordination was meeting our coordination time of 0.2 s to 0.3 s as usual. Now, with the PV, the corresponding fault current level increases. Therefore, it shifts to this right, and that leads to smaller coordination time between the relays as per the nature of IDMT curve. This coordinates time may be smaller than 0.2 s or so, and there may not be adequate operating time gap between the two relay.

Note that with the increase in PV capacity, the corresponding current level increases. Therefore, in IDMT curves, again it shifts for the right, and that may degrade the corresponding coordination furthermore.

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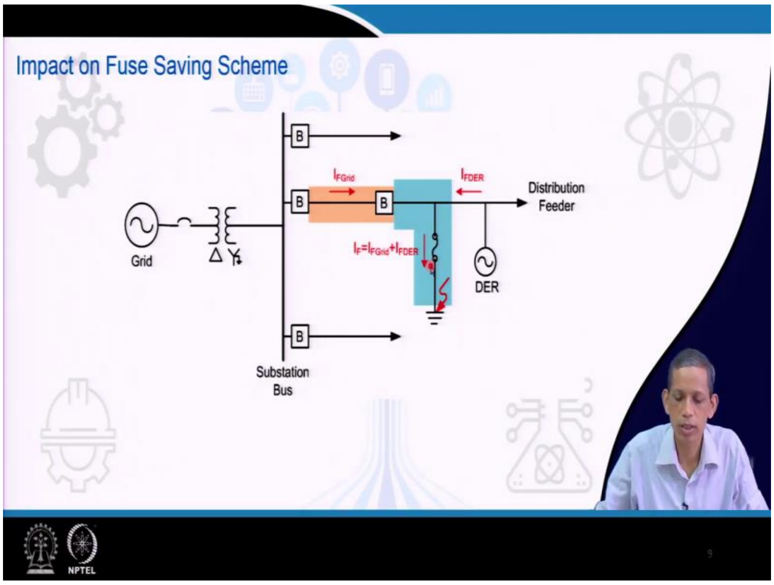

Now, we have also discussed the, in case of overcurrent principle also, the Fuse Saving Scheme. So, what happens in the fuse saving scheme is that in case of a downstream transient fault this fuse is not allowed to be blown out initially, so for that reason the corresponding upstream relay has an instantaneous protection and also an IDMT characteristics. The instantaneous relay operate first to make a judgment considering that the fault is transient in nature and then, it reverts back to the normal IDMT characteristics. By that, the fuse can be saved for most of the transient faults. Therefore, the restoration time becomes less, and there is no need for the crew people to go for the replacement of the fuse. So, that is what the principle of fuse saving scheme is.

Now, what happens, with DER connected beyond this line then the distributed energy resource PV or wind will contribute for this fault in this downstream. So, within that transient period, the level of fault current becomes more, and the corresponding fuse might be blown out even for that same transient faults also. And that is what, the fuse saving scheme is being under scrutiny in that situation also.

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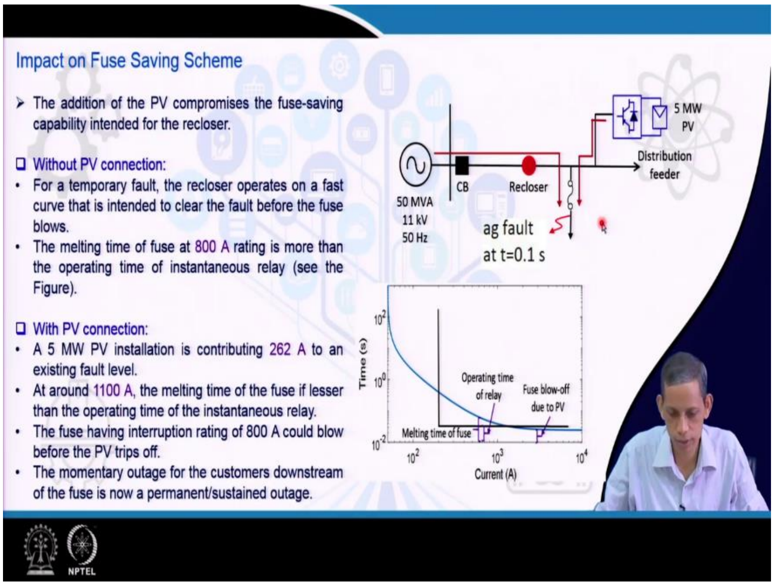

Let us come to an example in this situation. So here, we have the fuse here and fault happens to be here and then fault current is contributed from this side, and also from this 11 kV system Now what happens, we have a huge characteristics that in the blue, we have instantaneous protection, first one. Now, we have learned in our fuse savings schemes that this instantaneous protection should act faster than the fuse, then only the fuse can be saved for this fault.

Therefore, you can say here, that the operating time of the relay must be smaller than by the fuse time, and that must be there. Now what happens in this case when the PV penetration becomes more then the current through this faulted path becomes more. It goes to this IDMT characteristics of this fuse or almost the IDMT characteristics of the fuse. It goes to the higher current, and this higher current leads to a point like this, where this current may lead to a situation where the fuse blown out period may be smaller than the instantaneous protective relay characteristics. And that is what we see here, without PV connections, it was leading to at 800 A melting time of the fuse. With PV connection, the corresponding current becomes 1100 A and the issue will present. And that leads to a suggestion that the fuse may be blown out before the instantaneous operation. And in that case, the corresponding fuse saving scheme is under scrutiny it may not operate as expected. What we see from these situations is that in that situations such kind of schemes are under scrutiny with renewable integration in these systems. So, we have to see whether the functionality of such schemes will be correct or not correct with the higher and higher level of penetration of renewable resources.

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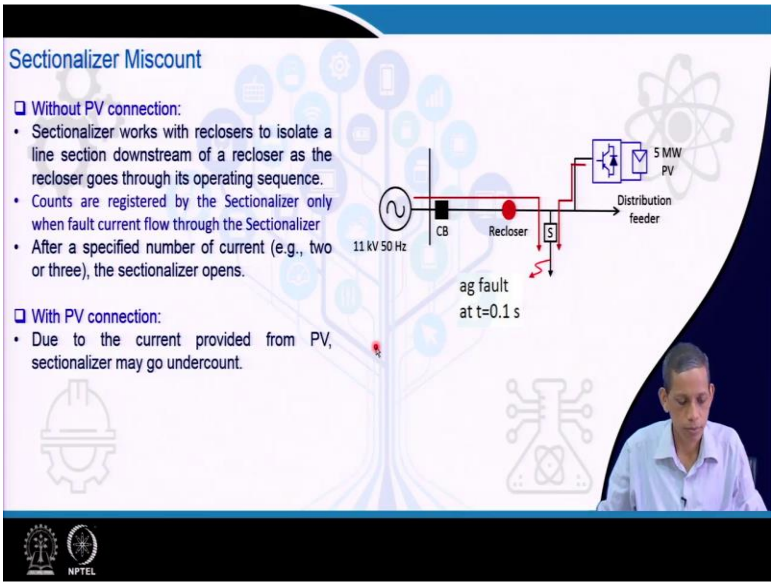

Now, coming to another issue on Sectionalizer. As we have already mentioned for the earlier classes, we know sectionalizer and reclosure, they have a coordination between them. So, the sectionalizer is connected to a downstream feeder with the probability of having more number of faults in that one, like a rural feeder or so. That may not hamper to critical loads like as the hospital load or any important load. So, in that situation this sectionalizer helps in that way. So, what it does in terms of a downstream fault happens to be there, the recloser assumes it is a temporary fault, and the recloser operates multiple times, 2 or 3 depending upon as per the setting. Now this fault here, the sectionalizer counts the number of interruption by the recloser, and if it finds the corresponding current to be higher in this path, then while the recloser has opened at some time, the sectionalizer opens and clears the fault. Thereby, the other sections in the distribution system restore the supply very quickly. This helps in the reliability of the systems. That is what it is being used in the system. Now, what we see here, with DER connected in this situation, so what will happen that for this permanent fault in this section, the corresponding fault current flows through this path continuously and in the recloser side, the current flows here. So, even the recloser is here this current flows, therefore, sectionalizer will not be able to see the interruption of current. It means that the number of counts, the number of counts upon which the sectionalizer decides will be now will be a different one, and that is what we talk about the miscount by the sectionalizer. Once again, that the sectionalizer counts the number of interruptions by the recloser, but the current contributed by this PV will not allow this interruption of current through the sectionalizer.

So the number of counts by the sectionalizer will be not correct as it has been designed for, without consideration of the PV and that will lead to improper operation of the sectionalizer. Therefore, it is already mentioned for earlier issues of related to renewable resources or DERs. So, we have to verify for systems before more and more renewables being integrated in the systems on the sectionalizer performance also.

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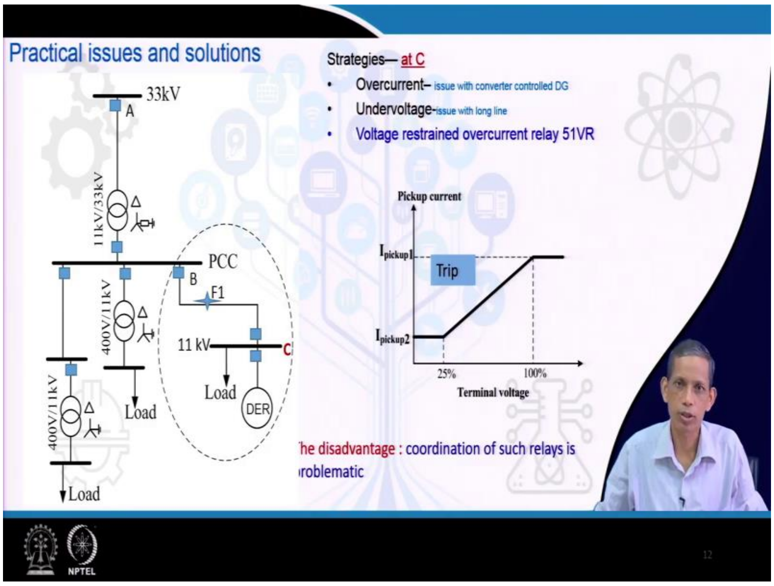

Now, one other is, we see these 33 kV systems, we have further ground downstream consider, 11kV systems, 400 V systems, LT system and so. Now, see here, what is the protection solution in that kind of perspective. One literature suggests, suppose we have a distribution system, that having renewable resources DER and then load connected at this 11 kV system also, some 5 MW or so. And then at this bus, we are observing at C bus, what is the corresponding relay performance for the breaker. Now, what happens that there are multiple options here, one is that the overcurrent relay. But we know that the DER will not able to pass on large amount of current, so overcurrent relay is under scrutiny, but this you can say that the relay is associated with this breaker. Now, there is another option, you can say that whenever a fault happens to be there in this line, then we expect that the voltage of this bus will be down.

So, we are talking about under voltage issue. But if this line becomes longer and fault happens to be towards the PCC bus or the bus B, then we can say that this degrade in voltage or lowering of voltage will be not significant, and the undervoltage relay here may not be able to pick up. So, then you can say that, neither you can say that overcurrent or under voltage finds the finds the proper fault in this line in such a scenario.

So, in that kind of things, the different perspective is being drawn, and that is you can say is called voltage restrained overcurrent relay, used for different application perspective, but here it can be applied in terms of that 51VR. So, in this case, the corresponding current becomes an adaptive one. So, depending upon the terminal voltage that is at the bus C, the corresponding pickup current depends upon the level of voltage. So, whenever a fault happens to be here, the voltage here may go down and note that the corresponding DER feeds the corresponding load and the excess amount of current flows towards the fault. And depending upon that, the corresponding voltage dip and all these things, normally what happens there suppose there is no load, then this corresponding DER will feed all currents to this side, PCC side. So, that you can say, this is a normal functioning. 100 % current will be seen by the relay even at the normal rated voltage also. So, that is a normal situation. So, whenever a fault happens to be there and the load is being fed by the DER, then the corresponding fault current flowing through this path may be substantially low and we can say that with a lower voltage, the corresponding pickup, current setting is lower in that perspective. So, this is about the trip region in this case and this is the block region in this perspective and all these things. And that is termed as voltage restrained overcurrent relay principle can be applied in case of such environment. But the problem we can say is that such an approach has issue or coordination issues and all these things. So, at multiple of places, if we apply this that becomes challenging. So, what we try to figure out here is that, there are related solutions, but that may be partial, it may not be complete solutions to the perspective because DER with inverter interface may not provide significant current.

So, overcurrent relay is under scrutiny and different perspective of challenges in overcurrent relay, we observe in the earlier slides. And also, under voltage relay performance may be limited, then the whole protection scheme of the distribution systems with higher and higher level of penetration is under scrutiny

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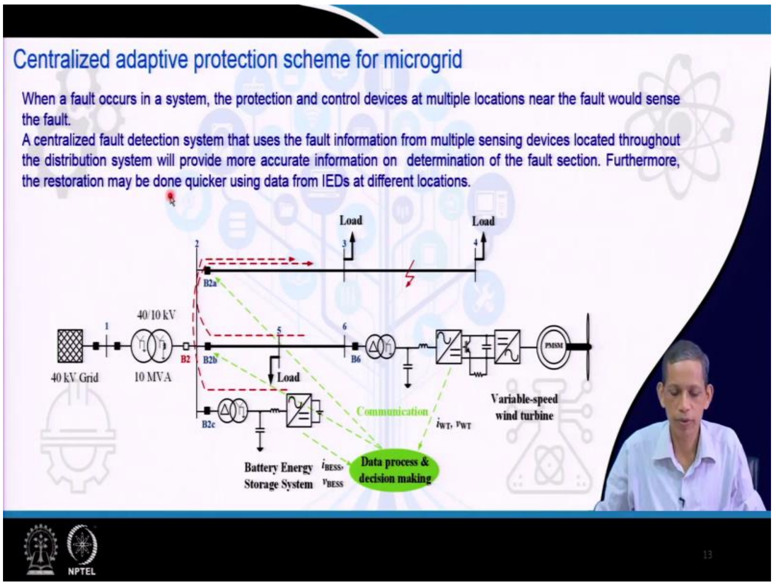

The others schemes, which is evolving considered in these kind of things is the concept of microgrid, which can be also extended to the distribution system also is on the perspective of communication assisted relay, communications assisted protection schemes, where we have is centralized protections schemes and we can collect data from different IEDs of the systems.

Now, what is the benefit of this? When a fault occurs in the systems, the protection and control devices or the IEDs in the systems at multiple locations of the systems, observe the corresponding fault situations and in particular, the IEDs near to the fault sense currents and voltage changes. And with the centralized mechanism. This information from such IEDs will be processed. Then we can infer the particular fault section in the system, where the fault has occurred then the command can be issued upon the particular breakers. Thereby, the selectivity, sensitivity of the systems can be improved also the restoration of the system can be quicker if we know the exact section and location of the fault from the information collected from different IEDs.

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So, in general, we say that the distribution system network protection schemes are being affected by the presence of these DERs, the inverter interface generators, sources, proper coordination, recloser actions, fuse performance, fuse saving methods, all form of overcurrent principles are under scrutiny. Presence of DERs needs special attention as regard to distribution system protection.

And in particular, with more and more DER is being integrated in the systems, the level of penetration is increasing day by day. The protection schemes are under scrutiny and they may require an alternative solutions in that perspective. Thank you.