Power System Protection
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Lecture No. 45
Fault Characteristics of Renewable Sources

Welcome to the Power System Protection course. We will go to the new module on Network Protection with Renewable Sources.

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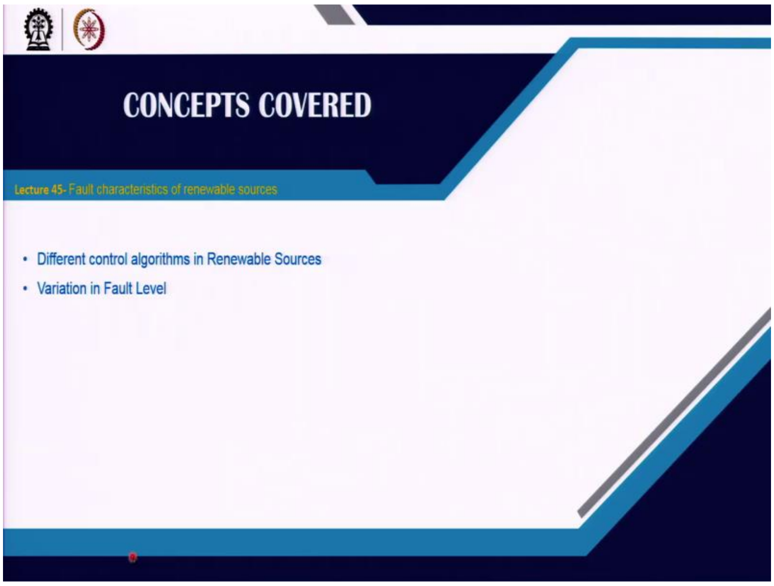

CONCEPTS COVERED

Lecture 45- Fault characteristics of renewable sources

- Different control algorithms in Renewable Sources
- Variation in Fault Level

In this lecture, we will see the different fault characteristics of renewable sources, how they are different from the conventional synchronous based source, how the fault level varies in different situations when you include renewable sources at different nodes in a power systems, both at distribution level or at high voltage level.

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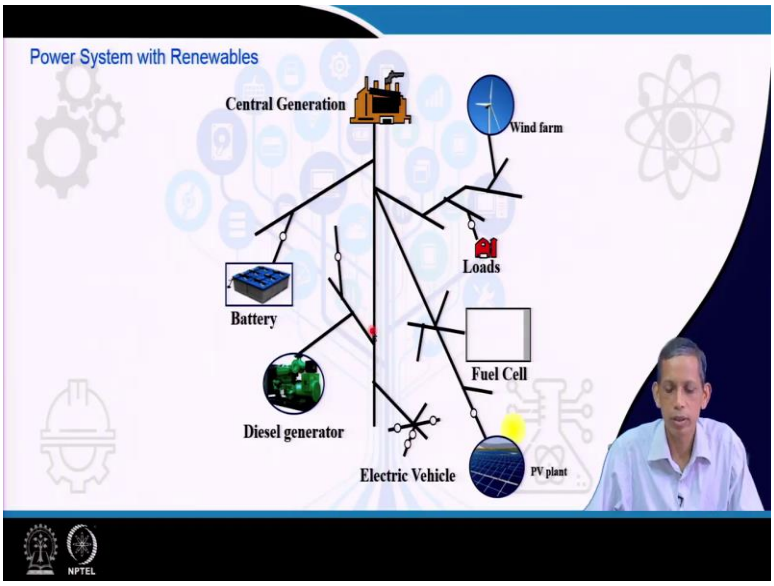

Power System with Renewables

Let us come to a power system, where conventional have central form of bulk power generation, now we have renewable sources like photovoltaic plant, wind farm, in the distribution system, also we can have a diesel generator, storage in the form of battery, fuel cell, electric vehicles integrated to distribution system. So, today's power system seek these kinds of renewable resources form photovoltaic or wind or small scale water based plant, hydro plant in this systems due to the environmental perspective also from the reliability perspective.

Now, what we observe today is that they are being integrated at small scale level in different distribution systems. Also large scale wind farm, photovoltaic plants are integrated at the high voltage grid. So, that leads to different scenario in the power system. The penetration level of such renewable resources is increasing day by day. That threats the available protection systems in the current power grid network, why and how that we will try to see here, consequently what are the possible mitigation strategy in term to that. This scenario is evolving, and therefore the corresponding protection system also is being in the development process and so. Now, whenever a fault happens to be in such systems anywhere, let us say at this point, then we said earlier that the conventional power generation is centralized and providing the fault current, now all the resources here will also participate in the fault current unless they are being withdrawn. So, in low voltage distribution system they may island themselves in a stipulated time. If that did not happens in high voltage level, because of the recurrent of grid code and operational perspective, then all such sources will participate in the fault current.

So, that becomes a different scenario, what we are observing in our earlier discussions on network protection. So, this module leads on network protection in the presence of such renewable resources, which is a now the era.

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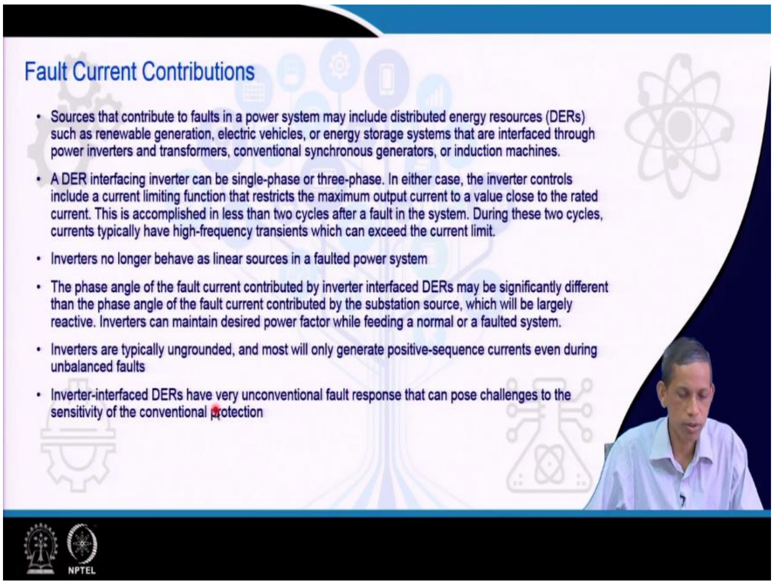

Fault Current Contributions

- Sources that contribute to faults in a power system may include distributed energy resources (DERs) such as renewable generation, electric vehicles, or energy storage systems that are interfaced through power inverters and transformers, conventional synchronous generators, or induction machines.
- A DER interfacing inverter can be single-phase or three-phase. In either case, the inverter controls include a current limiting function that restricts the maximum output current to a value close to the rated current. This is accomplished in less than two cycles after a fault in the system. During these two cycles, currents typically have high-frequency transients which can exceed the current limit.
- Inverters no longer behave as linear sources in a faulted power system
- The phase angle of the fault current contributed by inverter interfaced DERs may be significantly different than the phase angle of the fault current contributed by the substation source, which will be largely reactive. Inverters can maintain desired power factor while feeding a normal or a faulted system.
- Inverters are typically ungrounded, and most will only generate positive-sequence currents even during unbalanced faults
- Inverter-interfaced DERs have very unconventional fault response that can pose challenges to the sensitivity of the conventional protection

Now, all the perspective of protection is related to what we are discussing on sound faults, where the corresponding current expected to be high and we termed that as fault current. And you notice that this fault current is being contributed by all these resources present in the grid when they are being connected to the system during an event of fault. So, they contribute to this fault, may include all the distributed energy sources, we put a name as DERs here. And such renewable generations maybe including electric vehicles to storage to all these renewable sources like photovoltaic plant and wind farm. And we say, these DERs are mostly connected via the inverters and with the support of the transformers to the grid. The conventional synchronous generator also may be there in few in numbers in the system. And the fault also contributed by these induction machines in the system. Now, in this discussion, we will consider these distributed energy sources or DERs are connected into the grid considering inverters. So, they are inverter based DERs. These DERs can be of very low voltage system, can be of single-phase system kind of thing in our houses and so. It can be a 3-phase connections. Whatever it may be, the corresponding control includes limiting current functions to restrict the corresponding maximum output current, otherwise the inverter will be in trouble. The inverter's specific that the fault current should not exceed, otherwise it will be damaged. This corresponding current limiting functions will be as fast as possible for the safety of the corresponding inverters. Typically, in the current scenario, this current limiting is being accomplished in less than 2 cycles, even though ideally or theoretically, the corresponding control can be instantaneous also. As far the availability of inverters, they have different strategy of controls. So, during the fault the current limiting functions will be observed in this transient process in different type of inverters.

During these 2 cycles, current typically have high frequency transients, which we can say that exceed the current limit of the inverters, but that is within the tolerance limit of the inverter. Now, these inverters are no more behave like normal synchronous machine-based sources. The phase angle of the fault current contributed by such inverter based DER is significantly different than the phase angle of the fault current contributed by the normal synchronous machine-based grid, substation or so. The inverters can maintain desired power factor while feeding a normal or a faulted system. We see in earlier discussions that in the grid-based system when fault happens to be there the corresponding power factor was govern by the X/ R ratio of the network. However, in the case of inverter-based perspective, it can maintain a power factor as per the control strategy. Typically, inverters are ungrounded, and mostly they generate only positive sequence currents. There may not be negative sequence current or zero sequence current in that situation. That is a completely different scenario than what we discussed in our earlier protection principles based on this negative sequence current, zero sequence current. Inverters-interfaced DERs have very unconventional fault response or characteristics. That is the reason, it requires attention to the available protection schemes in the network.

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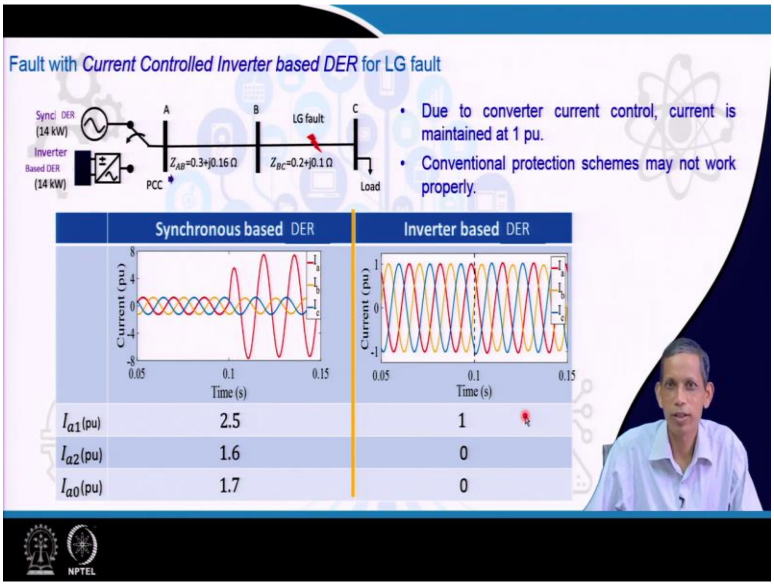
Fault with *Current Controlled Inverter based DER* for LG fault

- Due to converter current control, current is maintained at 1 pu.
- Conventional protection schemes may not work properly.

	Synchronous based DER	Inverter based DER
I_{a1}(pu)	2.5	1
I_{a2}(pu)	1.6	0
I_{a0}(pu)	1.7	0

Let us come to the fault current characteristics. So in an inverter-based DER, so we have line to ground fault. Let us this is simple network and in this network, we have synchronous machine-based DER, and we have inverter-based DER. Same capacity assumed 14 kW or so. This is a network and it create a phase-*a* to ground fault. Then we connect the sources individually, one by one. So, when the synchronous-based DER is there, that is what the conventional thing, then the corresponding phase-*a* current shoots up. And that is what we have seen in our earlier all discussions. So, at that time, we say that the corresponding positive sequence, negative sequence and zero sequence components will be there. For a phase-*a* to ground fault during fault path, all the 3 sequence currents remain same, but these are the measurements at the relay point, so this positive sequence component also include the pre-fault current, that is the load component of current, also the corresponding negative sequence and zero sequence current will be there and that of similar value.

Now, for an inverter-based DER, see the situation, the fault inception is the dotted line here, 0.1 s, right hand. During the fault the phase-*a* current is no more high, and this is due to the balanced nature maintained by the DER and due to the current limiting formation. So, this is current control inverter-based DER. The current is being controlled, and the corresponding phase currents are balanced, even though the situation is an unbalanced fault in the line.

So, in this case, we observed that when we have removed this synchronous machine and only operating only the inverter-based DER. There is no negative sequence current, no zero-sequence current, the current is perfectly balanced. So, this is an ideal condition. However, presently available inverters and all these things may take a time of typically 1 cycles to 2 cycles to settle down to this kind of values.

So, in this scenario, whatever it may be, the, there is a great difference between the fault characteristics in inverter based DER than the conventional one, and that is the problem associated with the protection schemes, because we consider in earlier all our discussions, that whenever a phase-*a* to ground fault happens to be there, the corresponding current happens to be like this, associated negative and zero sequence current happens to be in this kind of scenario, but no more negative sequence and zero sequence current here. Think straightforward, that the conventional directional relay using the negative sequence or the zero sequence components will not get any such sequence components. So, how can you use that directional link concept? That means that the conventional protection schemes are under scrutiny, are under question. And we will see that kind of situations in subsequent slides and discussion also.

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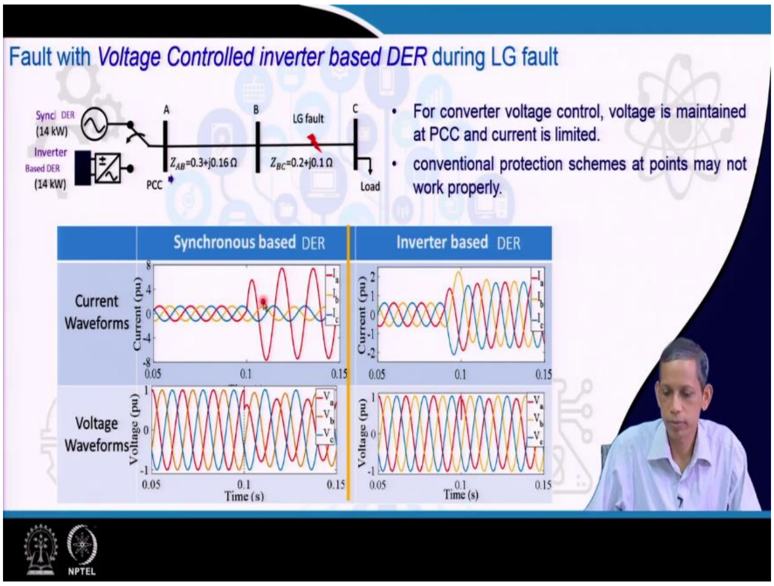

Fault with *Voltage Controlled inverter based DER* during LG fault

- For converter voltage control, voltage is maintained at PCC and current is limited.
- conventional protection schemes at points may not work properly.

Now, let us say, the corresponding inverter-based DER is voltage control inverter-based DER. So, what you like to say here, that in the inverter, we have numerous control options and the different control option is here and for same line to ground fault or the same position, we say for the synchronous machine based DER and the associated voltage, so phase-*a* voltage decreases and phase-*a* current increases. Now see here, the situation, the current has some little disturbance and then again almost balance. See the voltage, the voltage is almost balanced spontaneously following the inception of fault.

Therefore, you see clearly here from these 2 examples in earlier slide and this one, that in the voltage signal and the current signals, the inverter-based DER characteristics show altogether a different perspective than as compared to the conventional grid-based approach having synchronous machines in the system. Thus, we can claim here that the corresponding voltage and the current waveform are significantly different as compared to the conventional synchronous machine-based system.

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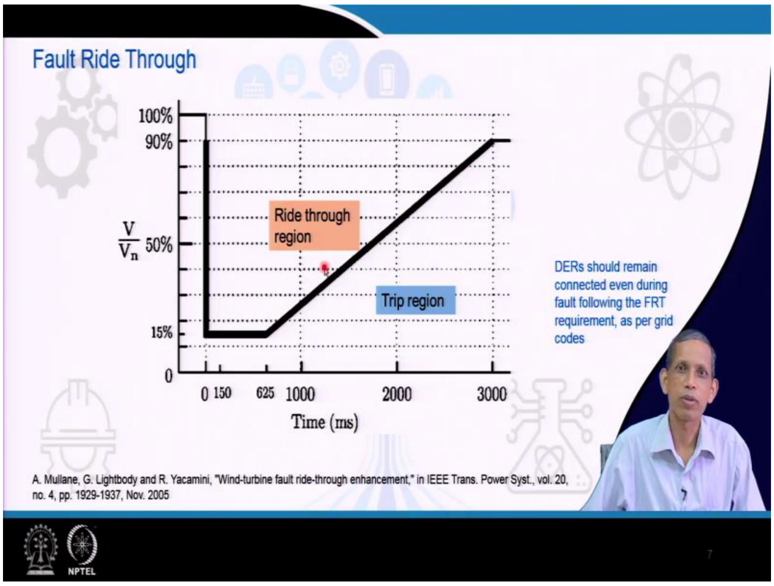

Fault Ride Through

DERs should remain connected even during fault following the FRT requirement, as per grid codes

A. Mullane, G. Lightbody and R. Yacamini, "Wind-turbine fault ride-through enhancement," in IEEE Trans. Power Syst., vol. 20, no. 4, pp. 1929-1937, Nov. 2005

There are other related issues also, that at low voltage level, these distributed energy resources may, are allowed to be disconnected. But at high voltage level, the amount of contribution of this corresponding renewable resource is very high, and they are no more being allowed to be disconnected from the system, otherwise the stability issue will arise.

Therefore, fault ride through comes from the grid code perspective. So, one such characteristic curve is provided here for this fault ride through. So, what we see that, if this is voltage versus time during the fault, so if the voltage dips below this, yes, the renewable resource is allowed to be withdrawn from the system. But if the voltage is higher than this corresponding resource is not allowed to be withdrawn, it has to support the grid. So, that is what the ride through region, the, above this curve, and below this curve, it can be withdrawn, it is allowed to be withdrawn on such a scenario. So, what we like to say that, DER should remain connected even during a fault following the FRT requirements, as per the grid codes in the high voltage systems. The corresponding energy resources are being connected to the grid following this kind of FRT characteristics.

It means that they will participate in the fault in case of low voltage system like for 400 V or so in our distribution system they may be allowed to be withdrawn from the system. So, in a steady state perspective, they may not participate in the fault. But with penetration level increasing day by day the grid code may be going down to the low voltage system also.

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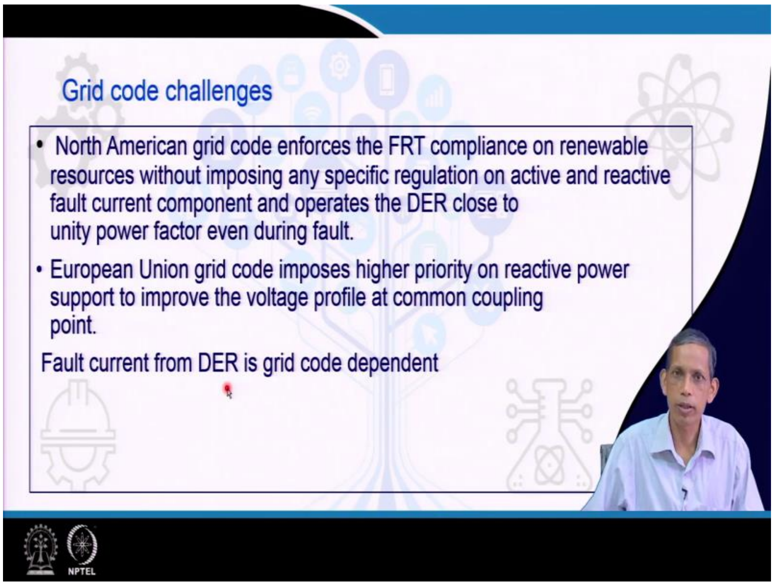

Grid code challenges

- North American grid code enforces the FRT compliance on renewable resources without imposing any specific regulation on active and reactive fault current component and operates the DER close to unity power factor even during fault.
- European Union grid code imposes higher priority on reactive power support to improve the voltage profile at common coupling point.

Fault current from DER is grid code dependent

These grid code puts further challenges to the system. They have their own variations like the North American grid code enforces the fault ride-through compliance on renewable sources without imposing any specific regulation on active and reactive current component. During the FRT, how much reactive current, how much fault current will be there? No imposition in the North American grid code. And operates the DER close to unity power factor even during fault. It asks for the DER to operate the corresponding situations even unity power factor region.

European Union grid code imposes high priority on reactive power because the voltage is low. To support the voltage, such grid code asks for reactive power support and to improve the voltage profile at common coupling point. See here, it does not maintain the unity power factor situation or so.

So, this is about the big difference between different grid codes. Indian grid code recently has introduced similar to that of the European Union grid code characteristics. Fault current from DER is grid code dependent that is what another conclusion, we are deriving from this above two grid codes.

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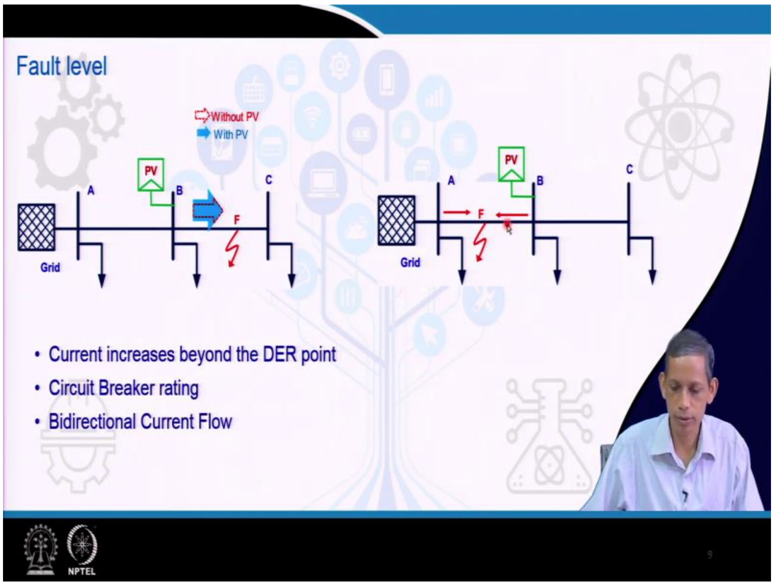

Fault level

- Current increases beyond the DER point
- Circuit Breaker rating
- Bidirectional Current Flow

Now let us see fault level. So, this is a normal substation or grid and we have a distribution system or transmission system, any level and we have connected a PV source here with inverter based connection to the grid. And we have fault here. So, what will happen? When PV was not there, so in the red dotted line, this is the level of current that was flowing only from grid to the fault, when PV will be there during the daytime or so to the fault.

At this point, fault current will be flowing from the grid and also additional fault current will be flowing from PV also. So, at this point, the corresponding fault current will increase. So, we say, without PV, the corresponding fault current is smaller amount at this point. And with PV, the fault current increases. That means, at this B point, the circuit breaker will see large amount of current. So, with PV capacity going on increasing here, who knows whether the circuit breaker has that capacity to withstand that level of fault current or not.

That means we have to see the corresponding circuit breaker rating, we have to check the corresponding circuit rating upon the corresponding renewable resource capacity going on increasing in the system. Take this next issue and a fault happens to be there between bus A and B in the same system. So, without PV, fault current was flowing from here to here only. Now, with the presence of PV, fault current will flow from here to here also. Now, what does it mean? If the PV continues to be there in the system, avoiding the FRT or fault ride through we essentially require a breaker here to isolate this corresponding PV for this fault, otherwise fault will continue from this site.

So, that means that the radial nature of the system for fault, because without this PV, fault current was flowing from the side to this side. So, we have breaker here and breaker here also. Now, to disconnect the PV for this fault, we essentially require the breaker here. So, breaker here means, breaker here, and breaker here means, we require directional relay to be also incorporated at this bus B also. So, that, the bi-directional current flow is another issue in this perspective. In the first case, we saw current amount to be higher. And in second case, we saw that bi-directional power flow is another protection issue, which requires different kind of attention.

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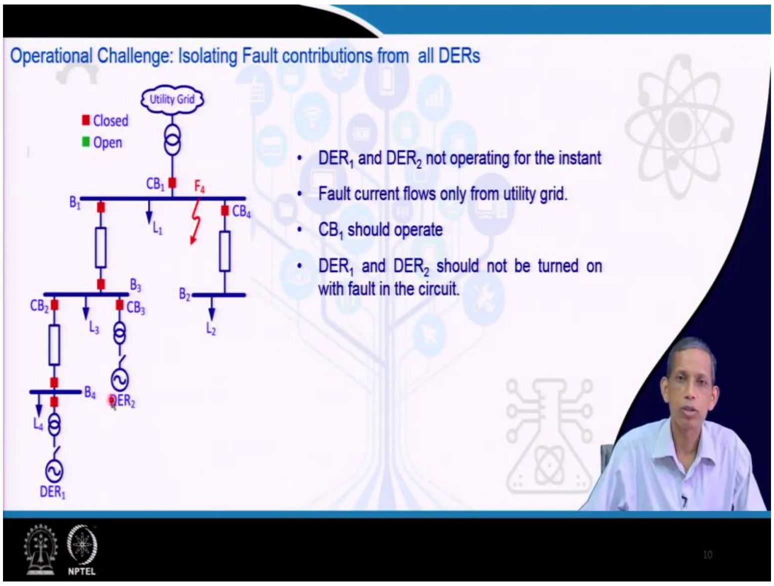

Operational Challenge: Isolating Fault contributions from all DERs

- DER$_1$ and DER$_2$ not operating for the instant
- Fault current flows only from utility grid.
- CB$_1$ should operate
- DER$_1$ and DER$_2$ should not be turned on with fault in the circuit.

On operational challenges in a distribution or a network perspective, now this is about isolating fault from the DERs. Now, let us see, a fault happens to be at F$_4$ at this bus. Then from the utility grid, this circuit breaker 1 should be open as this feeding the power. Assume that DERs are not available at night time, PV may or not be available also, now the question is that if the corresponding DER will be switched onto this fault, then this DER will be feeding to this F$_4$. So, that results in that question that whenever a fault starts, fault F$_4$ happens to be there, these DER should not be switched on. It means that the corresponding associated circuit breaker CB$_3$ and CB$_2$ must be switched off. Even though the associated current was not high or they were switched off, so whenever the corresponding fault happens to be at F$_4$, information should be available and the corresponding circuit breaker with the DER should be switched off, otherwise they will be switched on to the fault.

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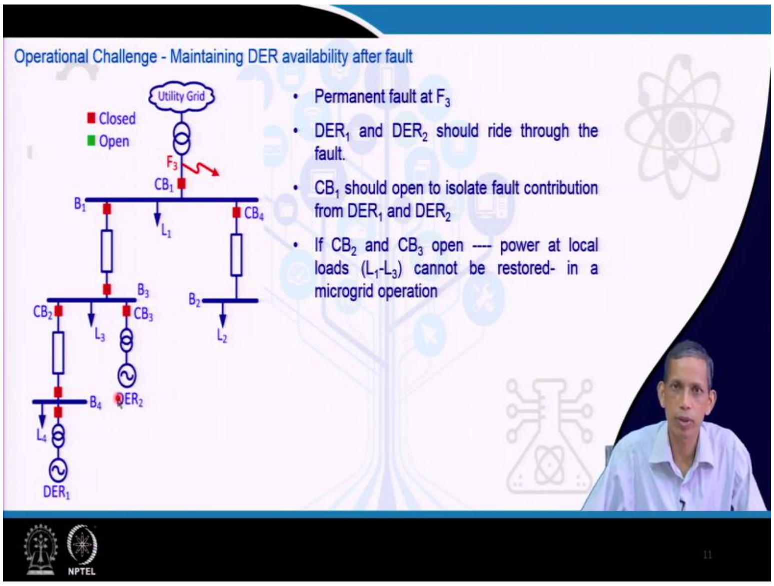

Operational Challenge - Maintaining DER availability after fault

- Permanent fault at F_3
- DER_1 and DER_2 should ride through the fault.
- CB_1 should open to isolate fault contribution from DER_1 and DER_2
- If CB_2 and CB_3 open ---- power at local loads (L_1-L_3) cannot be restored- in a microgrid operation

Further challenges, you see here, let us say, permanent fault at F_3, it means that if these DERs are there, this circuit CB_1 should be open. Now, if we like to maintain the integrity of this portion using this corresponding DER concept of microgrid then the circuit breaker 2 should and circuit breaker 3 should be open if they will not be able to meet the load. If they will be able to meet the load, this will not be open. So, that is the point that if the microgrid operation will be successful, then the corresponding DER should be maintained. If that will not be successful, this will be withdrawn. So, these are other challenges. Microgrid is altogether a different domain of activity, which is evolving today in the low voltage system perspective and so,

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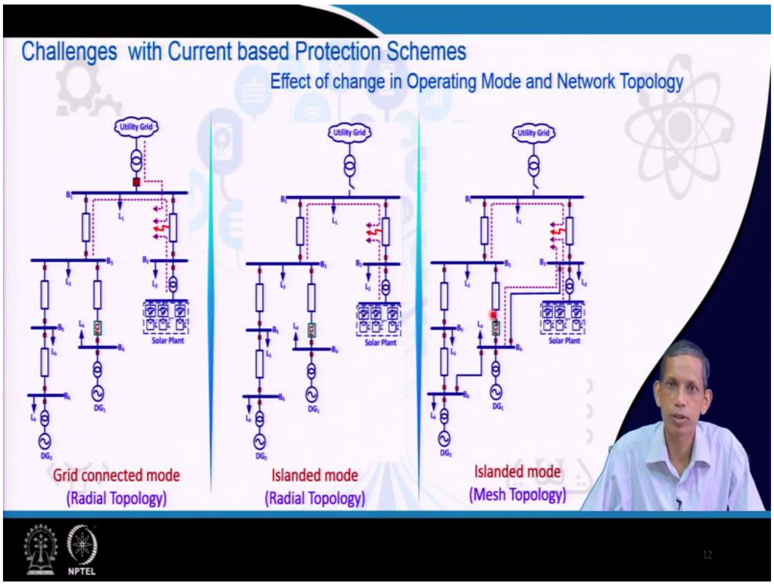

Challenges with Current based Protection Schemes

Effect of change in Operating Mode and Network Topology

Grid connected mode
(Radial Topology)

Islanded mode
(Radial Topology)

Islanded mode
(Mesh Topology)

Now, what are the current based schemes and how they are being under scrutiny in this kind of scenario? So, we can say a situation, a fault happens to be in this system at this point, so it will lead to agree to participate to the fault. DERs from this also will participate, solar plant from this also will participate. So, to this fault all the sources, from all the perspective will provide the corresponding fault current to this path. So, FCL here, fault current limiter, somewhere fault current limiter may be there also to limit the current of the fault path or the system. So, this is a grid connected mode and this is a radial topology typically in terms of that.

Now, suppose you can say grid is disconnected because of this the fault happens to be there, the grid is disconnected. And then, we have, this whole system is being managed by these renewable resources and other resources available here. So, in this case, what happens, this breaker here will now see a current from this side and a current from this side will be for this breaker. In earlier case, this breaker observing the current from the utility grid. Note that the utility grid current level is very-very high because utility capacity is much higher than this circuit capacity level. So, that makes a big difference to the breaker and associated relay. Now, go to the islanded mode, another topology, operation in mesh topology. So here, in this case, there is a connection between this bus to this bus, bus B_2 to bus B_4. So, in this perspective, if the grid is isolated the current flows from this side and also the current flows from this side to this side also. Thus the corresponding breaker here, we see a different amount of current than what it was observing from at this point without the connection between B_2 and B_4. So, the point of concern here is that depending upon the grid connections depending upon the topology of the system and so, the corresponding level of currents at different breakers and associated relays will be different. It puts challenges to the different overcurrent principle or so in the low voltage system and similar challenge will be there in the high voltage system also.

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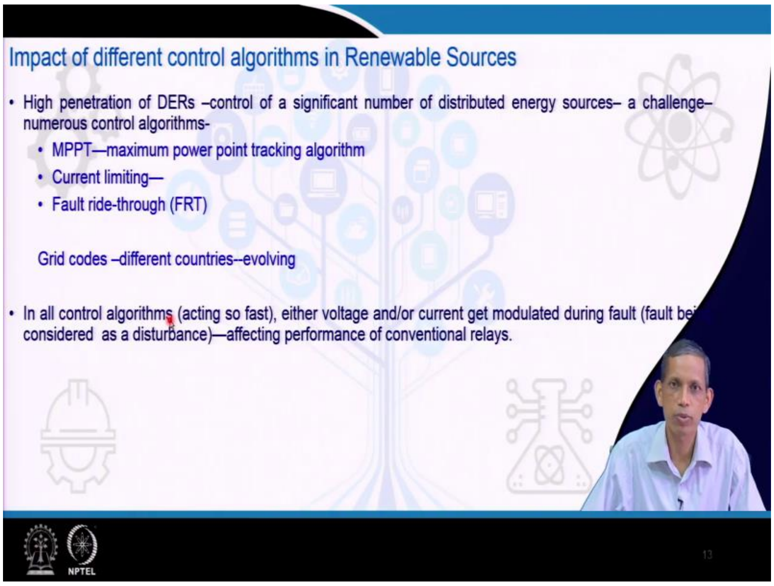

Impact of different control algorithms in Renewable Sources

- High penetration of DERs –control of a significant number of distributed energy sources– a challenge– numerous control algorithms-
  - MPPT—maximum power point tracking algorithm
  - Current limiting—
  - Fault ride-through (FRT)

  Grid codes –different countries--evolving

- In all control algorithms (acting so fast), either voltage and/or current get modulated during fault (fault be considered as a disturbance)—affecting performance of conventional relays.

So, we know the different control algorithms embedded in the inverters through which the renewable resource feeds to the grid. It can have maximum power point tracking algorithm. Essentially, it has current limiting features. Fault-ride through as per the grid codes. Different grid codes have different fault-ride through principles. Again, grid codes are changing and day by day. So, what we like to say that all the control algorithms, they act very fast. Either voltage or current gets modulated during the fault. And thereby, because the control algorithms, they do ride very fast ideally, instantaneously or the corresponding current or voltage are being limited or current are being controlled in a cycle or so. And that is what the period, where the corresponding protection or the relay decision is being carried out.

So, the speed of this operation of this controller is so fast that during which the corresponding protection scheme is being activated. Therefore, the controller action embedded in the inverter is a pretty important factor while studying the required nature of the fault characteristics and associated protection scheme for the system.

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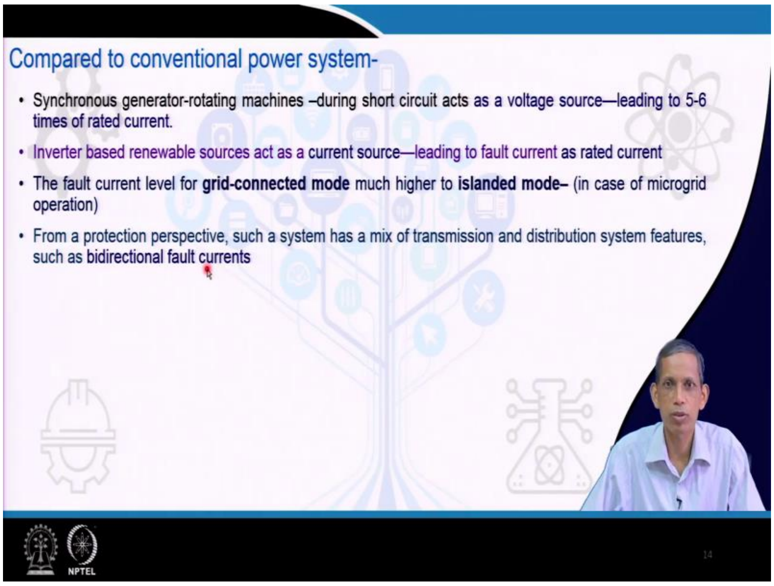

Compared to conventional power system-

- Synchronous generator-rotating machines –during short circuit acts as a voltage source—leading to 5-6 times of rated current.
- Inverter based renewable sources act as a current source—leading to fault current as rated current
- The fault current level for **grid-connected mode** much higher to **islanded mode**– (in case of microgrid operation)
- From a protection perspective, such a system has a mix of transmission and distribution system features, such as bidirectional fault currents

So thus, compared to the conventional power system, the synchronous generator rotating machines during short circuit provides typically 5 to 6 times of the fault current or rated current. Inverter-based renewable resource acts as a current source unlike a synchronous machine based voltage source. It is a current source, and leads to fault current to the rated current of the inverter, which may be the corresponding full load current also. The fault current of the grid connected mode in a system, we observed, that is much higher when it is in islanded mode in case of microgrid applications or so.

From protection perspective, such system has a behaviour, characteristics is a combination of transmission and distribution like bi-directional power, bi-directional current flow during fault and so. So, these are numerous different scenarios, situations, which, we see as compared to the conventional power systems network protections, which we have already see in our earlier lectures.

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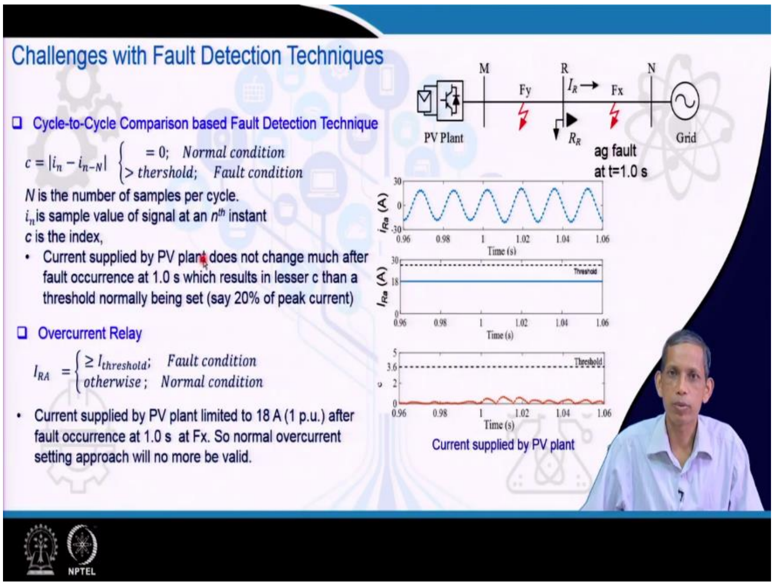

Challenges with Fault Detection Techniques

- ❑ Cycle-to-Cycle Comparison based Fault Detection Technique

$$c = |i_n - i_{n-N}| \begin{cases} = 0; & Normal\ condition \\ > thershold; & Fault\ condition \end{cases}$$

N is the number of samples per cycle.
i_n is sample value of signal at an n^{th} instant
c is the index,

- Current supplied by PV plant does not change much after fault occurrence at 1.0 s which results in lesser c than a threshold normally being set (say 20% of peak current)

- ❑ Overcurrent Relay

$$I_{RA} = \begin{cases} \geq I_{threshold}; & Fault\ condition \\ otherwise; & Normal\ condition \end{cases}$$

- Current supplied by PV plant limited to 18 A (1 p.u.) after fault occurrence at 1.0 s at Fx. So normal overcurrent setting approach will no more be valid.

Current supplied by PV plant

Simple fault detection techniques. We will learn point to, sample point to point comparison or cycle to cycle comparison. Let us say, cycle to cycle conversion. In cycle to cycle comparison, the current samples of current compared to the earlier one cycle earlier sample. So, that difference in magnitude is the indication of fault that we learn in very early classes. Now for this is PV plant connected with a grid via this bus M and we create an *ag* fault at F_X at 1 s. Then if you are observing at this relay bus. So, in phase *a*, fault happens to be there, this is the current pattern, this is the corresponding current you observe, threshold setting normally that will be something like that 20 % of the peak current. Now, with this we see that the corresponding index C, $|i_n - i_{n-N}|$ represented in this brown curve is very small value as compared to this normal threshold. Normal threshold means in a typical synchronous machine-based grid perspective. So, what we like to say here, that if we apply the same principle, then with the conventional threshold the fault detection will not work, even the conventional principle of cycle to cycle comparison is under scrutiny. Come to overcurrent relay, we already have seen that the current will not increase, but that means that the corresponding current, which you talk about here will not be high. Then how we will decide on the overcurrent principle? Will it work? What will happen to the coordination aspect of the different overcurrent relay in the system and so? Those all things are under scrutiny in this kind of renewable resources connected to inverters and transformer connections

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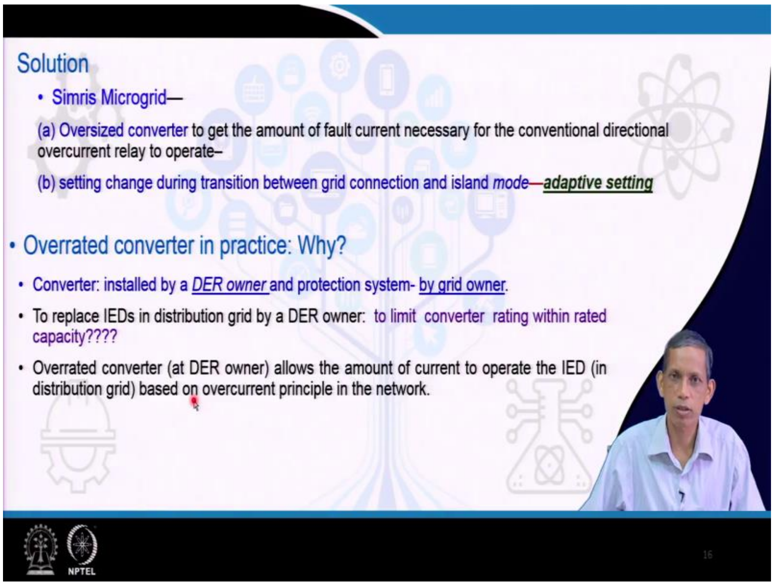

Solution

- Simris Microgrid—

(a) Oversized converter to get the amount of fault current necessary for the conventional directional overcurrent relay to operate–

(b) setting change during transition between grid connection and island *mode*—***adaptive setting***

- Overrated converter in practice: Why?
  - Converter: installed by a *DER owner* and protection system- by grid owner.
  - To replace IEDs in distribution grid by a DER owner: to limit converter rating within rated capacity????
  - Overrated converter (at DER owner) allows the amount of current to operate the IED (in distribution grid) based on overcurrent principle in the network.

Then what are the solutions? One of the application in *Simris Microgrid* is being done as solution perspective is the *Oversized Converter*. So, we see, what is the corresponding normal rating of that PV or wind source consider converter with rating more than that.

Then you allow the fault current to be higher and then overcurrent will function. But then that is associated cost of the converter. So, whether that is acceptable or not for the DER agency or not, that is another question. Furthermore, if it is a microgrid operation we know, the corresponding islanded operation case, the level of current becomes substantially low. So, what is being done in that Simris microgrid change the setting of this overcurrent relay whenever the grid is disconnected. So, that is one adaptive setting perspective. But that requires communication arrangement to release the reset command to another value. Now, one solution what you talk about, oversize converter in practice. So, if we generalize this to all application perspective to have overrated converters, then this will be installed by this DER owner, distributed energy resource owners but in the protection system, which is being there is by the grid owner. So, what we see, also that with more DERs in the system, the level of current increases. And the level of current increases means, the protection system is under scrutiny including the circuit breaker rating, for the circuit breaker and the protection scheme belongs to the grid owner, not to the DER owner. So, that is what the issue, who will take care, who will see on this perspective and so that includes economic and viability, feasibility perspective.

To replace corresponding protection scheme or IEDs in distribution grid by DER owner to limit the converter rating within rated capacity. Sometimes, for the functionality aspect of the available overcurrent or so, existing overcurrent relay or anything in the distribution system or so, the controller algorithm embedded in the inverter is being moved. So, that is one perspective or solution also. Overrated converter allows the amount of current to operate in IED. And that overcurrent principle will work successful. But it, can be extended to all such systems? That is the question.

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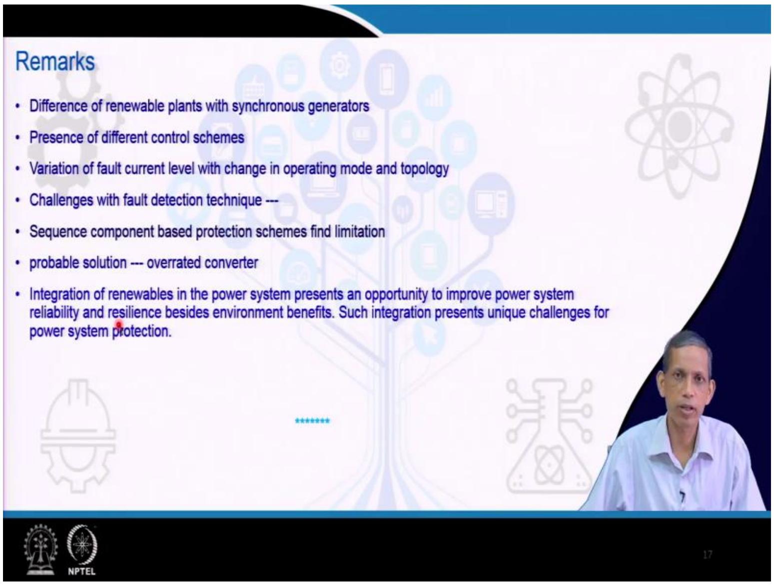

Remarks

- Difference of renewable plants with synchronous generators
- Presence of different control schemes
- Variation of fault current level with change in operating mode and topology
- Challenges with fault detection technique ---
- Sequence component based protection schemes find limitation
- probable solution --- overrated converter
- Integration of renewables in the power system presents an opportunity to improve power system reliability and resilience besides environment benefits. Such integration presents unique challenges for power system protection.

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So, our concluding remarks is that difference in renewable plants with the synchronous generator, what we say in terms of level of currents, in terms of bidirectional power flow, in terms of waveforms natures, fault characteristics of both current and voltages for different control schemes embedded in the inverter changes, modulates the corresponding currents and voltage differently.

Grid codes, we saw that also makes a difference whether the corresponding voltage and current will be operating in unity power factor mode or a different power factor mode that makes a difference. Variation of fault current level with changes in operating current mode and topology also are observed. Even during the daytime, the PV generations will be different.

Therefore, there will be variation in output power of the PV plant also. Those are operational perspective. Challenges with fault detection technique also we see, because the current modulation will be not high, furthermore, you can say that the current being balanced even during the phase *a* to ground fault, negative sequence, zero sequence current may not be available. Then how the different sequence component being used in general or to learn in our earlier discussion for network protections. At the end, we talk about a solution perspective to increase the rating of the converter, modulate the corresponding control actions such that the protection will not be hampered. So, these are possibilities, which we talk about. But there are other change the corresponding protection against that arrangements, replace the available protection schemes. So, those are the other consider alternatives and all these things. We will see in the subsequent classes also. But integration of renewables in the power systems presents an opportunity to improve power system reliability, resilience perspective, besides environmental benefits. And that is why, we find now increasing number of renewables, higher and higher high penetration level of renewables both at distribution level and at transmission levels. But we notice that such integration presents unique challenges for power system protections. The most important is that such inverter-based DER modulate the current and voltage signal significantly and very fast during which only the relay takes a decision. Thank you.