Digital Protection of Power System
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Lecture 39
Protection of Hybrid AC/DC Microgrid: Issues and Challenges

Hello friends. So, in this class, we will discuss about the protection issues and challenges faced by hybrid AC DC microgrid. So, we will consider first AC microgrid, then we will consider the DC microgrid and then we will also discuss the hybrid AC DC microgrid. So, let us see what is a microgrid.

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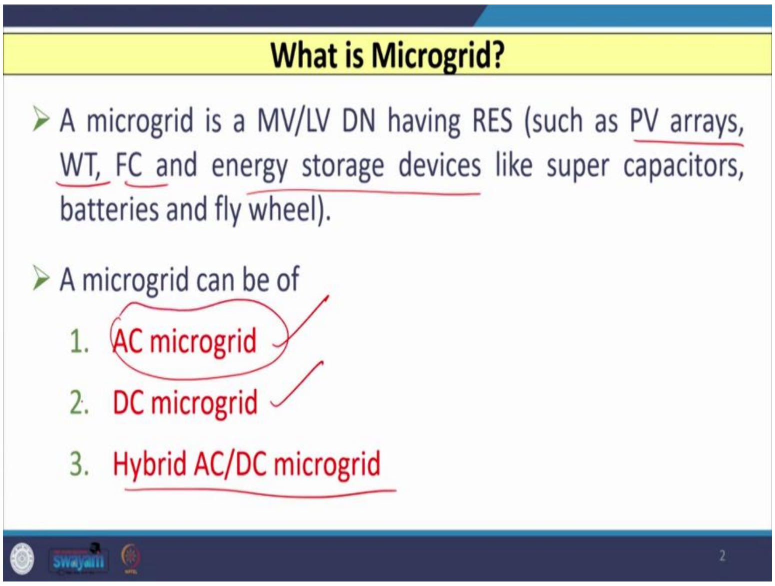

So, a microgrid is a medium voltage or low voltage distribution network having a renewable energy Sources as a distributed generators or distributed energy resources such as photovoltaic based generators, wind turbines, fuel cell and several energy storage devices like super capacitors, batteries and flywheels. So, as I told you, a microgrid can be AC microgrid, DC microgrid and hybrid AC DC microgrid.

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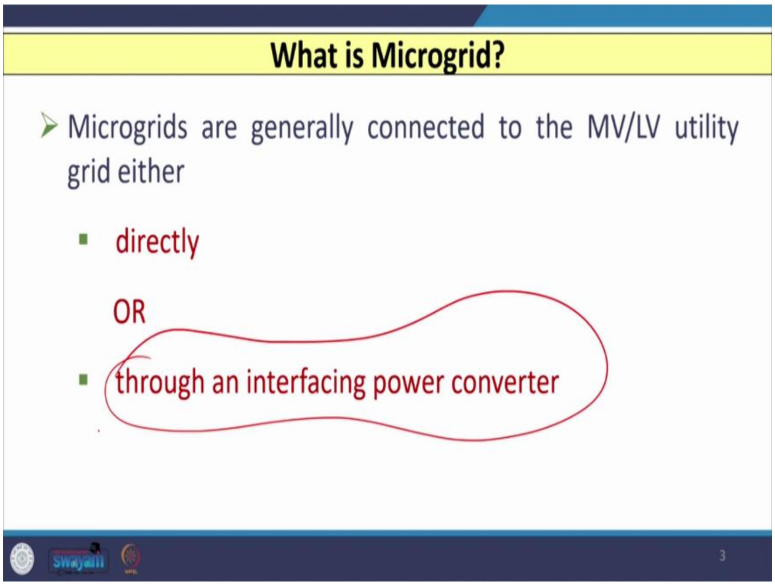

So, let us discuss first what is AC microgrid. So, as I told you microgrids are generally connected to the medium voltage or low voltage utility grid either directly or it can be connected through an inter facing power converter.

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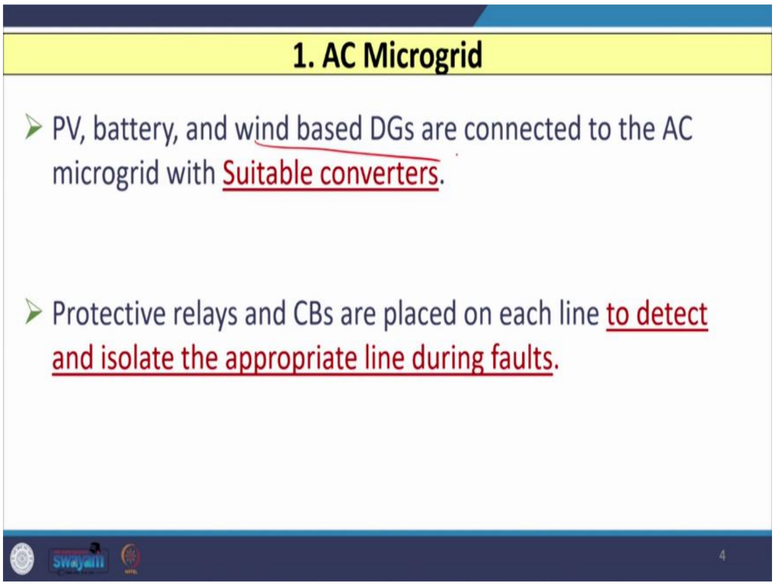

So, let us see what is AC microgrid. So, in AC microgrid photovoltaic, battery and wind based distributed energy resources are connected with suitable converters. So, protective relays and circuit breakers are also connected in a particular line. So, that whenever a fault occurs, we can detect the fault as well as we can isolate that line or section for the maintenance work and we can restore the power supply as early as possible. Now, let us see what is the structure of AC microgrid.

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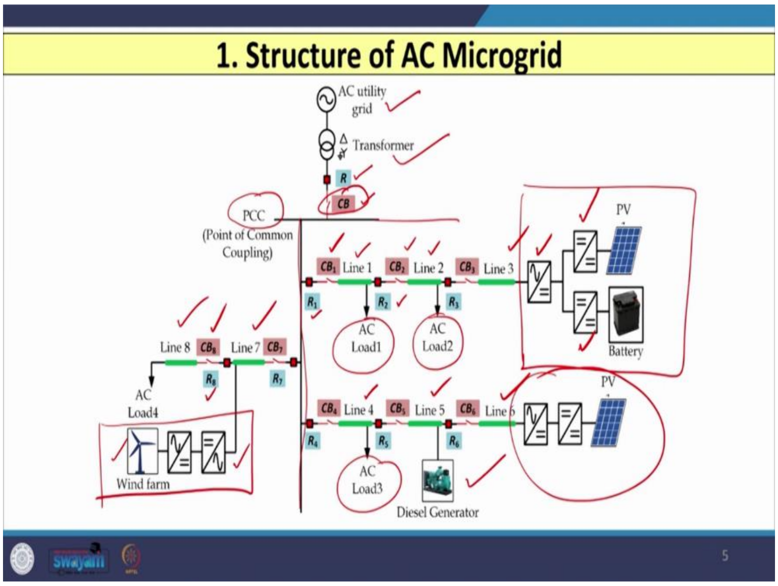

So, here the utility grid is there through the transformer, we have a bus which is known as point of common coupling. So, before point of common coupling, we have a relay along with the circuit breaker So, that if we wish to disconnect or isolate this utility grid from the rest of the system that we can do by opening this circuit breaker. Then we have feeder on which several lines are connected like we have line 1, line 2 and line 3, line 4, line 5, line 6, line 7 and line 8.

For each line, line 1 to line 8 you can see one separate relay let us say for line 1 it is R1 in circuit breaker one similarly for line 2, R2 and circuit breaker 2 and so on up to line 8 we have R8 and circuit breaker 8 they are installed. So, if any fault occurs in line 1, then relay R1 has to sense this fault and it has to give the signal to the circuit breaker 1 and circuit breaker 1 has to isolate the faulty section without affecting the remaining lines or healthy sections, several loads are also connected like AC load 1, AC load 2, AC load 3 and so on.

And on this side, you can see we have a PV based generator with battery they are connected with the converters here DC to DC converters are there first and then we have the DC to AC converters are there. So, we have a PV based generators we can connect directly diesel generator also or we can connect the wind farm also. So, we have a wind farm then we have AC to DC converter and then we have DC to AC converters. So, this is nothing but the structure of AC microgrid.

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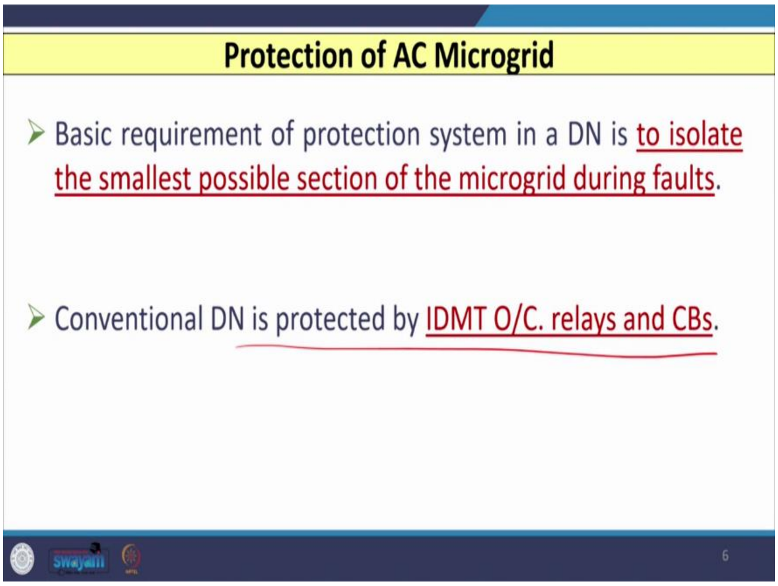

Now, let us see protection aspect of AC microgrid. So, the basic requirement of any protection system if we are using for distribution network is to isolate the smallest possible section of the microgrid during faulty situation. So, conventional distribution network is protected by inverse definite minimum time overcurrent relays associated with circuit breakers.

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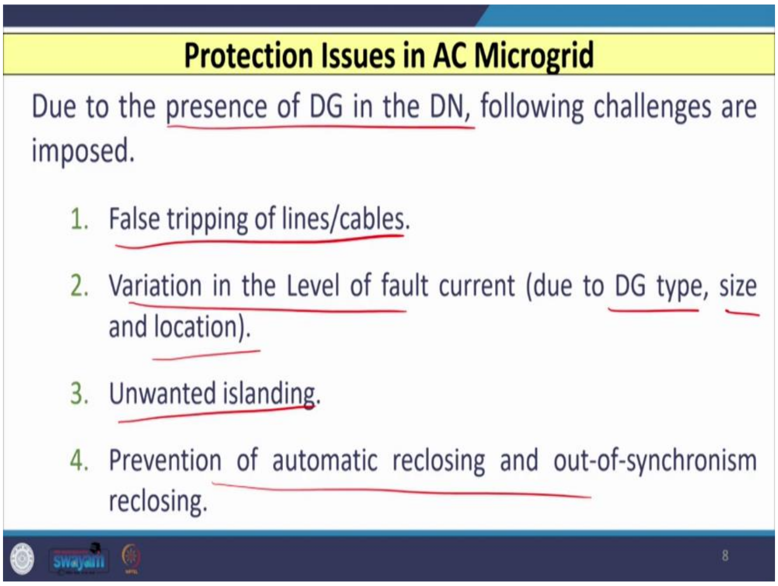

So, in the conventional distribution network, the protection coordination between the relays reclosers and fuses that is well established because the structure of this distribution network is radial in nature. However, whenever we introduced distributed energy resources in terms of solar wind or others, then the power flow in the distribution feeders no longer remains unidirectional, it becomes bidirectional. Hence, the coordination between the protective devices like relays, reclosers, fuses, that is either different or it can be partially lost or it can be completely lost depending upon the situation.

So, if I consider the what are the challenges for the AC microgrid, then because of the presence of distributed energy resources in the distribution network following challenges are faced by AC microgrid, the first is the false tripping of lines or cable. So, if fault is in line 1 then line 2 or line 3 may trip unnecessarily. Similarly, the second is the variation in the level of magnitude of fault current because of the type of DG, size of DG and the location of DG all the 3 are variable.

The third is the unwanted islanding and fourth is the prevention of automatic reclosing and out of synchronism reclosing. So, let us discuss first with the false tripping of lines or cables.

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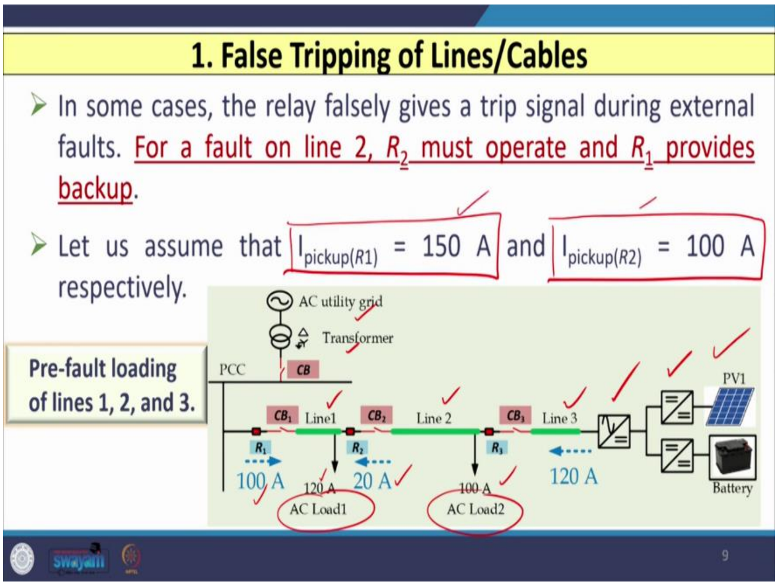

So, to understand this phenomenon, let us consider a network in which utility grid is there, which is connected at PCC through transformer and we have a line 1 line 2 and line 3 are connected with several loads AC load 1 and AC load 2 and on the right-hand side we have a PV based generator with battery which suitable converters are there that is DC to DC and DC to AC converters are there.

Now, let us assume that this load needs either 120 A current and 100 A current. So, that is supplied like this during pre-fault condition, the 100 A current will flow through relay R_1, 20 ampere current will flow through layer 2 and 120 A will flow through the relay R_3. So, let us assume that the pickup current of relay R_1 is 150 A. So, reliable picks up and sense is the fault if current exceeds about 150 A on primary side.

Similarly, through relay 2 the pickup current of relay R_2 is let us say 100 A and here 20 A and 100 A is flowing through R_2 and R_1. So, relay does not pick up in normal condition. So, both the relays do not pick up.

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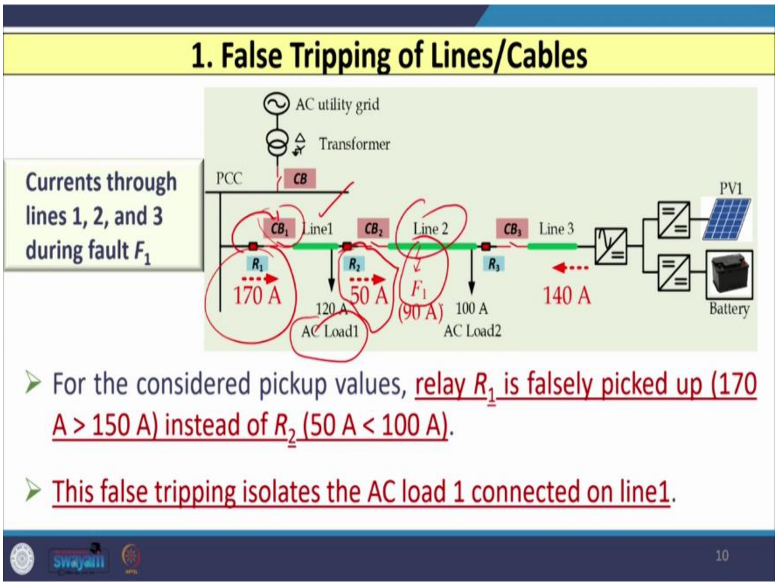

Now, let us say fault is going to occur on line 2 at F_1 with a current 90 A. So, there is a redistribution of current and now you can see through relay R_1 170 A current flows and through relay R_2 50 A current flows, the pickup setting of relay R_1 is 150 A. So, as 170 A is greater than 150 A. So, R_1 will picks up and it will initiate the command and your circuit breaker 1 that is going to isolate in this condition.

However, as relay R_2 pick up is 100 A which is lower than 50 A. So, R_2 relay will not pick up. So, here as the fault is in line 2, but as circuit breaker 1 is going to isolate because of that the other section will trip unnecessarily. So, this type of false tripping will isolate AC load 1 instead of the other line 2 where actually the fault is.

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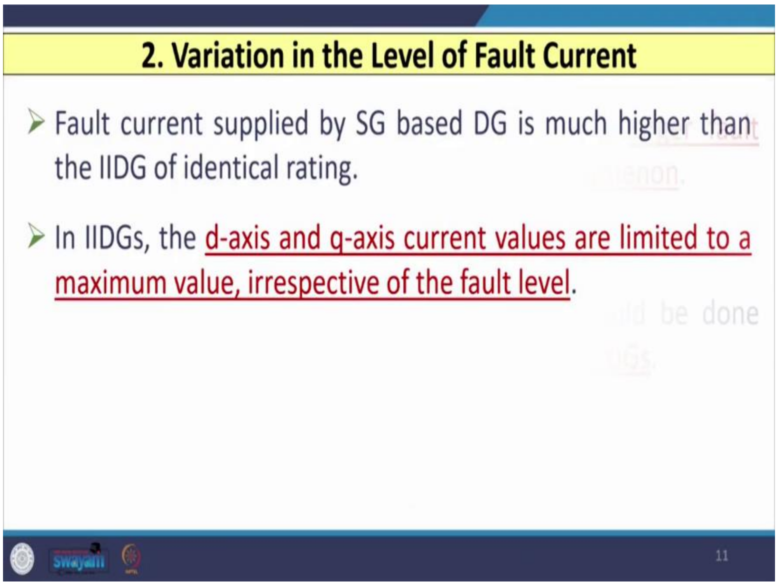

Now let us see the second issue variation in the level of fault current. So, we know that fault current supplied by the synchronous generator base distributed generator is much higher than the inverter interface distributed generators of the same rating. So, in case of inverter interface distributor generators, the d axis and q axis current values are limited to a maximum value irrespective of the fault level.

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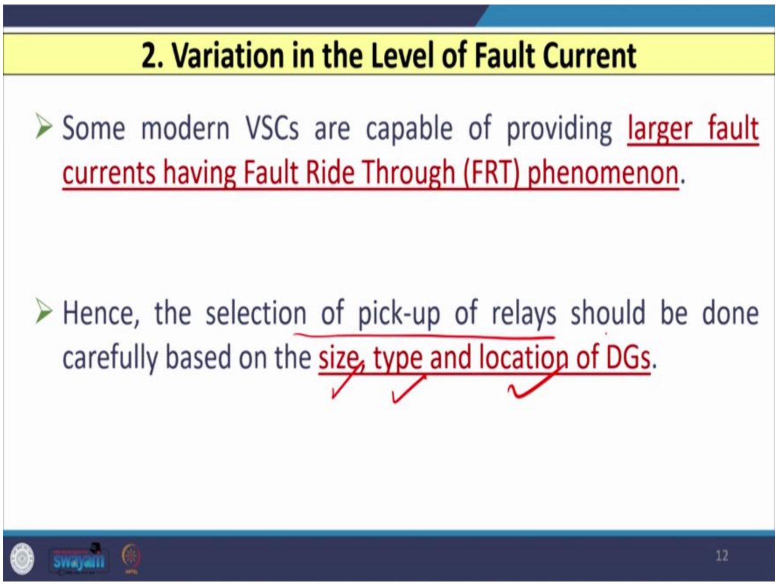

Some modern voltage source converters are capable of providing larger fault current having fault right through phenomena. Hence, when we select or decide pick up of the relays then we have to decide this very carefully based on the size, type and location of the distributed generators or distributed energy resources.

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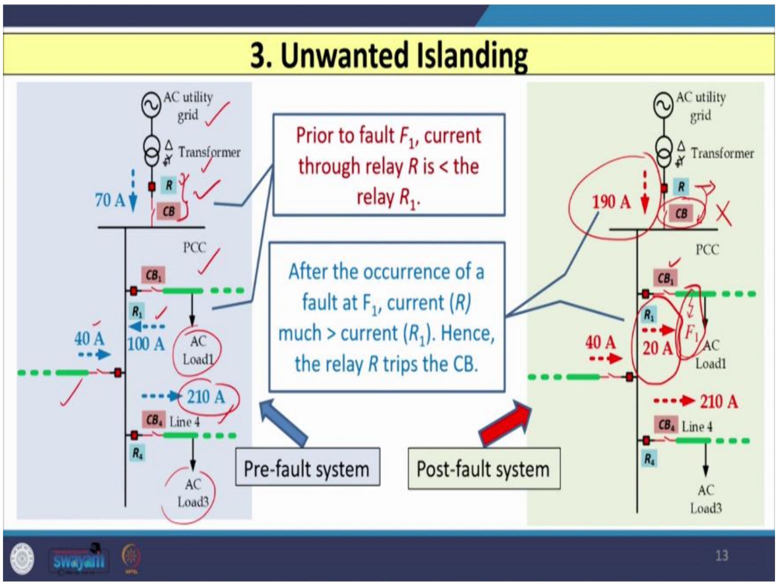

The third point is the unwanted islanding. So, to understand this phenomenon, let us consider one network which is fed by AC utility grid to the point of common coupling through this transformer. And here before PCC we have a relay and circuit breaker and the current through this relay R is 70 A in pre fault condition, we have several loads connected AC load 1, AC load 3 and so on. On 3 lines shown by green color and the distribution of current in pre fault conditions are such that the total current here that is 210 A.

So, here you can see that when there is no fault or during pre-fault condition, current through the relay R that is less than the current through the relay R_1 through relay R 70 A current is there whereas, through relay R_1 100 A current is there. However, on the same network which is shown on right hand side, if fault occurs at F_1 on this line, then the redistribution of current takes place and now you can see through relay R 190 A current flows whereas through relay R_1 Only 20 A current flows.

So, after the occurrence of fault at F_1 current through relay R is much higher than the current through relay R_1 190 ampere is greater than 20 A. Hence, this relay our sense is this fault at F_1 and it initiates the command and circuit breaker will trip this circuit breaker will trip unnecessarily as faulty is at F_1. So, circuit breaker 1 has to trip but instead of that circuit breaker this near to relay R before PCC that will trip. So, this is nothing but the unwanted islanding of the microgrid.

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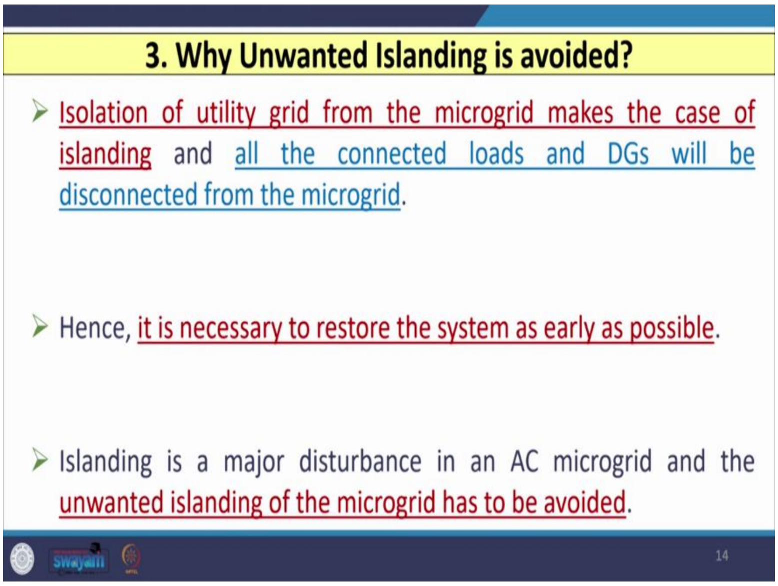

Now, isolation of utility grid from the microgrid that makes the case of islanding and all the connected loads and DGs will be disconnected from the microgrid. Hence, it is necessary to restore the system as early as possible. So, islanding is a major disturbance for AC microgrids and unwanted islanding that should be avoided as far as possible.

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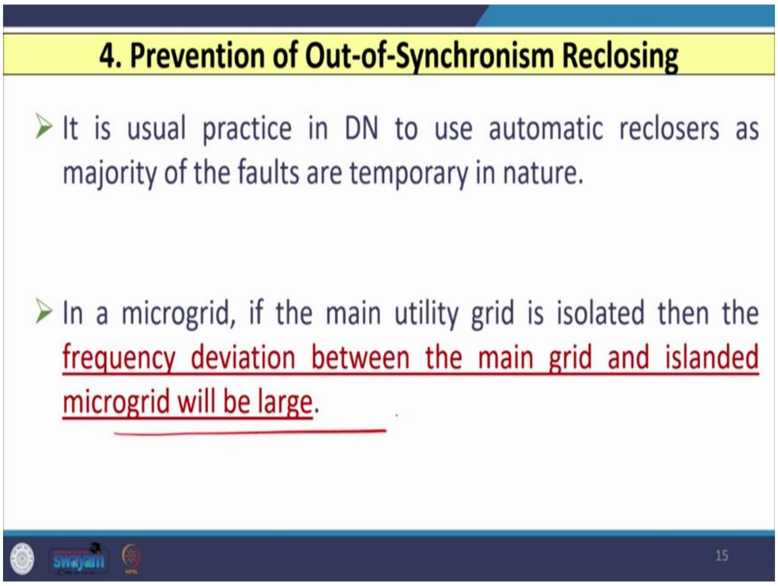

The fourth is the prevention of out of synchronism reclosing. Now, we know that it is usual practice in distribution network to use auto reclosers as majority of faults are temporary in nature 80 to 90 percent faults in distribution networks, they are temporary or transient in nature and they die out maybe after one cycle or one and a half cycle.

So, in a microgrid, we have to use automatic recloser. So, that if any fault occurs, we can reclose the whole of the circuit breaker and so that if fault is there, then they already die out and system becomes a normal condition or it is already there in the normal situation. So, if reclosing attempt is carried out in microgrid and when out of synchronism phenomena is there, because we know that when we reclose, the recloser are pole of the circuit breaker in this situation, then the frequency deviation is such that the actual degree of phase shift is almost 180 degrees.

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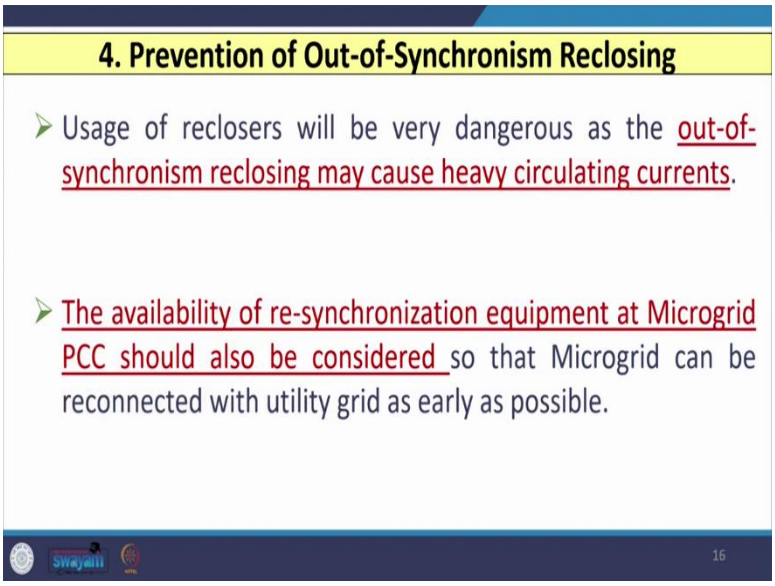

So, if we reclose this thing, then large circulating current fuel flows and that is going to damage the loads which we have connected in the distribution network or in the microgrid. So, availability of resynchronization equipment at microgrid PCC should be always considered. So, microgrid can be reconnected with utility as early as possible.

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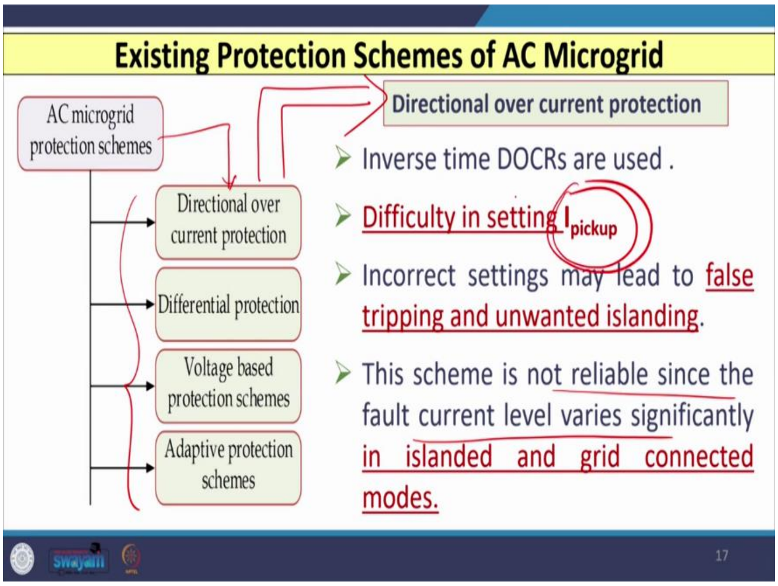

So, with this background, let us see what are the different protective schemes that is used in AC microgrid. So, for AC microgrid, the 4 different types of schemes are used and the first scheme is the directional overcurrent based protecting schemes. So, normally inverse time directional overcurrent relays are used in this case. However, it is very difficult to decide pick up of this relay when the different renewable energy sources as a distributed generators are connected and when power flow becomes bidirectional.

So, it is very difficult to decide the setting or pickup of the relay and hence incorrect setting may lead to false tripping and unwanted islanding if I use directional overcurrent-based protection scheme, this scheme is not reliable since the fault current level varies significantly when microgrid is walked in and islanded mode and in the other case when microgrid is working in a grid connected mode. So, it is very difficult to decide the pickup of the relay.

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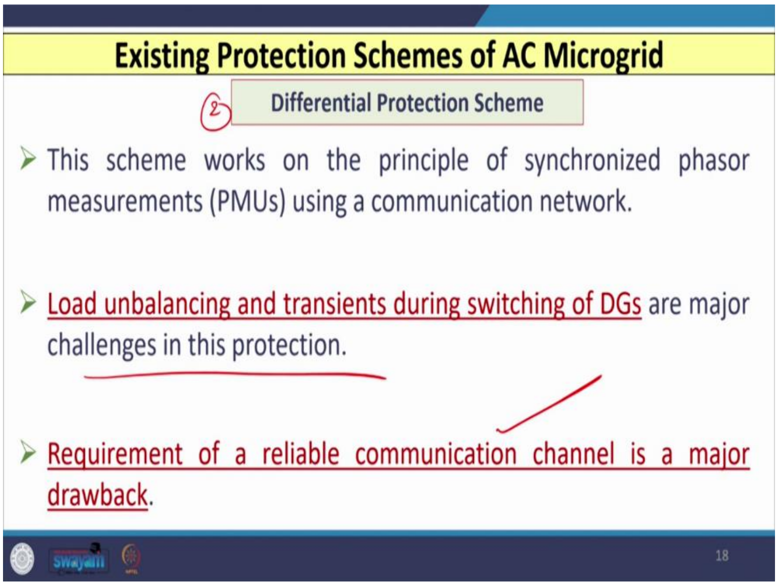

The second type of scheme that is known as differential protection schemes. So, in differential protection schemes, this scheme works on the principle of synchronized phasor measurements using a communication network. So, load balancing and transients during switching of different distributed energy resources are the major challenges for this type of protective scheme. And this scheme also requires a communication channel, which is a major drawback, if there is a failure of communication channel, then this scheme is not going to work and we have to use or we have to depend on some backup scheme.

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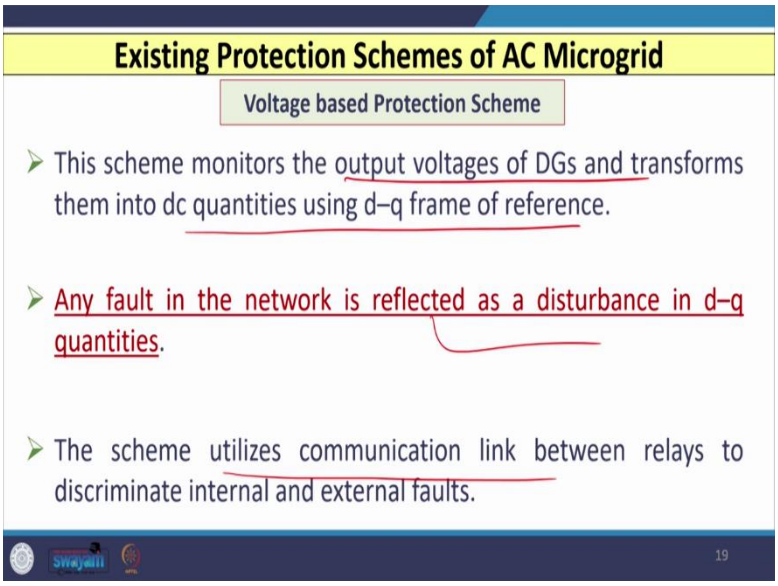

The third type of scheme that is known as voltage-based protection scheme. So, this scheme monitors the output voltage of the distributor generators and then transforms the face quantities into the d-q quantities. So, that any fault in the network is reflected as a disturbance in d-q quantities. So, this scheme utility is a communication link between relays to discriminate internal and external faults.

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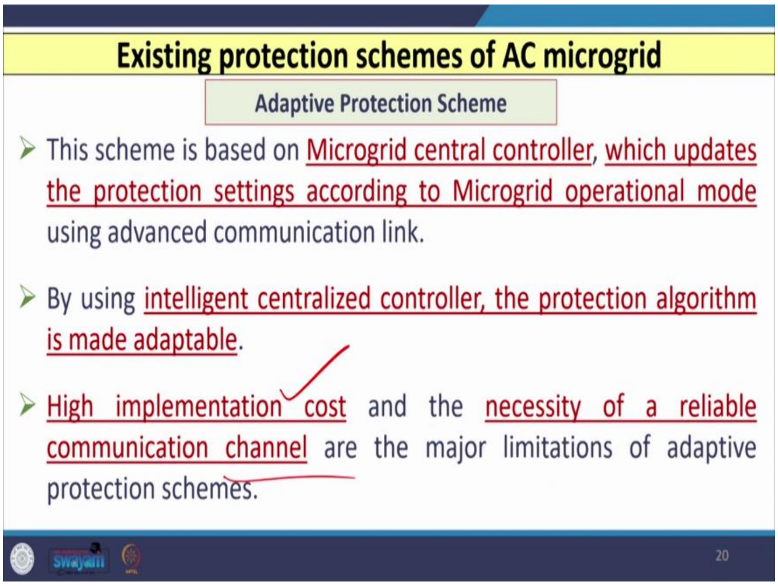

The fourth type of scheme that is adaptive protection scheme. So, this is the latest scheme and it works based on microgrid central controller, which updates the protection settings according to the microgrid operational mode using some communication medium. So, when microgrid is in islanded mode the setting will be different, when microgrid will be in grid connected mode, the setting will be different and this will be updated automatically without user intervention using communication link. By using intelligent centralized controller, the protection algorithm is made adaptable however, high implementation cost and necessity of a reliable communication channel are the major drawbacks of this type of scheme.

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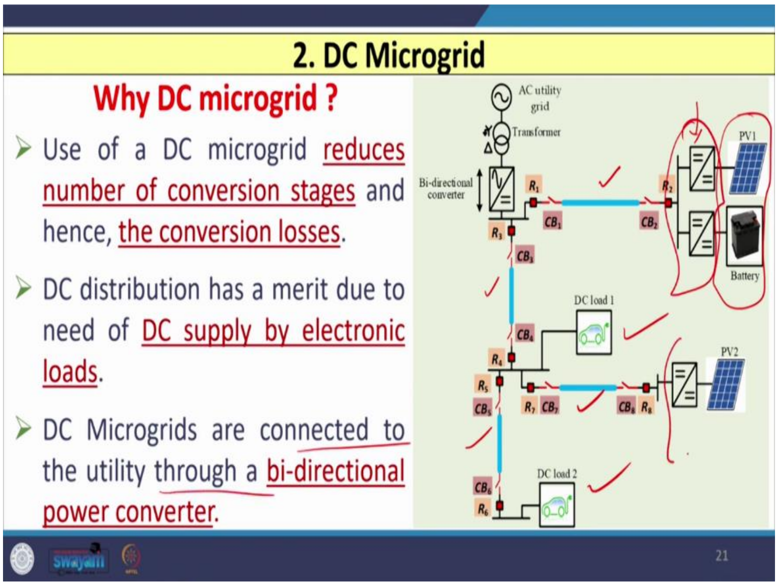

So, with this discussion, let us see what is DC microgrid. So, use of DC microgrid reduces number of conversion stages this is a structure of DC microgrid and you can see these blue lines these are the DC cables and this are connected with the PV based or battery-based generators through only DC to DC converters. Loads are directly connected because most of the loads electronics loads they require DC supply. So, if I use DC microgrid then that is going to reduce the number of conversion cases, which in turn reduces the conversion losses. DC microgrid are connected to the utility through a bi-directional power converter as shown here.

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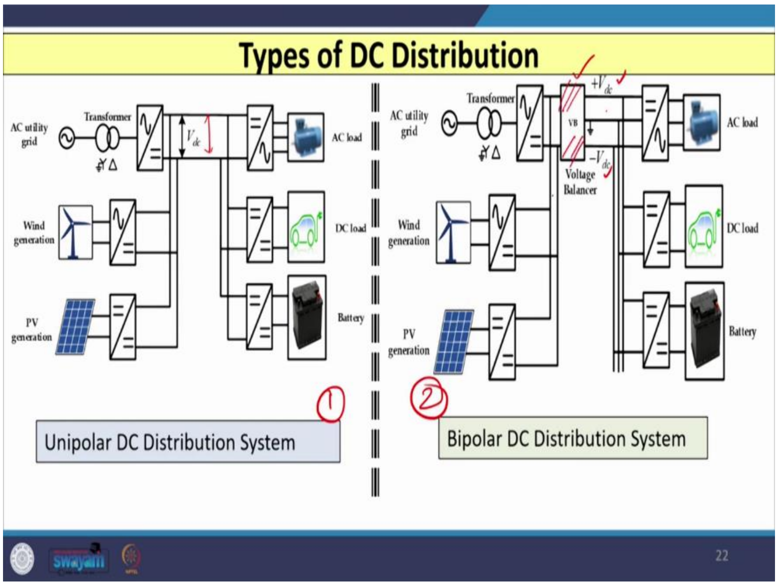

Now, let us see what are the types of DC distribution. So, there are 2 types of DC distribution. The first is the unipolar DC distribution system and second is the bipolar DC distribution system. The difference is here you can see that in unipolar DC distribution system only one voltage level is there.

Whereas, in bipolar DC distribution system you have $+V_{dc}$, $-V_{dc}$ in between you have this neutral wire and 2 V_{dc} is also there. Here in unipolar DC distribution system, there is no voltage balancing circuit whereas, in bipolar DC distribution system, you have a block which is known as VB block that is voltage balancer block and after that all the loads are connected here.

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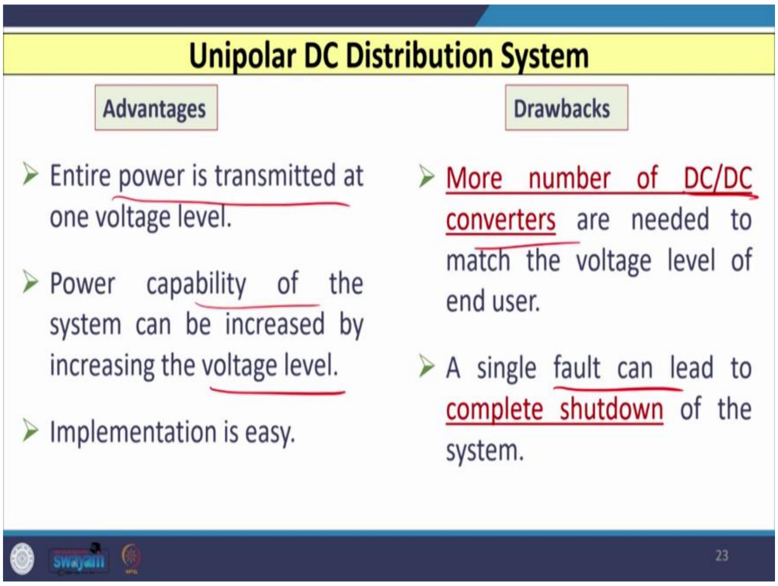

So, if I consider the unipolar DC distribution system, then the advantage of this system is entire power is transmitted at single voltage level power capability of the system that can be increased by increasing the voltage level and its implementation is easy. However, more number of DC to DC converters are needed in this case which is a prime limitation of unipolar DC distribution system, a single fault if it is going to occur on unipolar DC distribution system or network that is going to completely shut down the whole network in this case.

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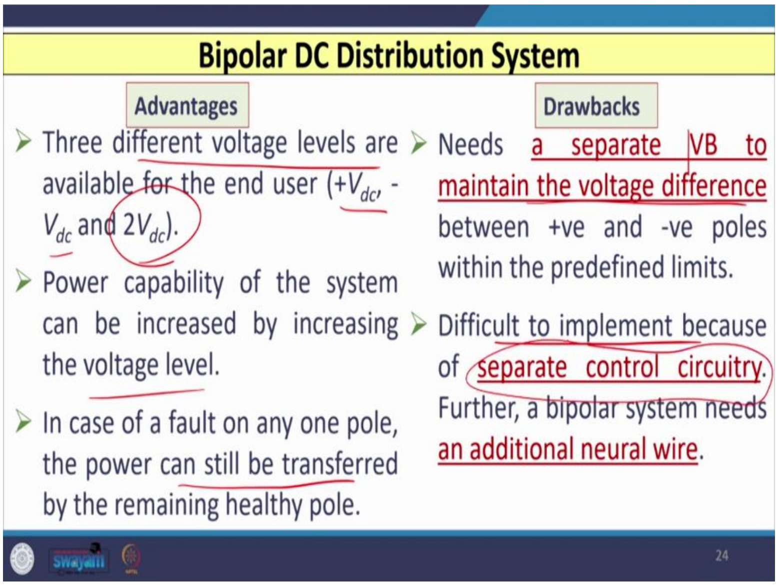

However, if I consider the bipolar DC distribution system, the advantages are 3 different voltage levels are available $+V_{dc}$, $-V_{dc}$ and $2V_{dc}$ power capability of the system that can be increased by increasing voltage level and in case of fault on any one pole, the power can still be transmitted by the remaining healthy pole. So, this is the main advantage of bipolar DC distribution system.

However, these bipolar DC distribution system needs a separate voltage balancer circuit to maintain the voltage difference between positive and negative poles within some prescribed limit and it is difficult to implement this type of scheme because this type of scheme needs a separate control circuit and further it also requires an additional neutral wire this wire that is for bipolar DC distribution system.

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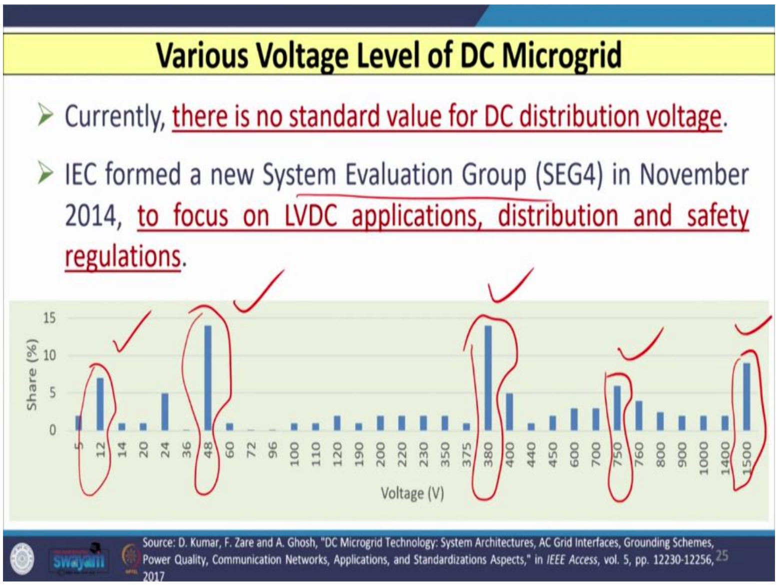

Now, let us see what are the various voltage levels available for DC microgrid. So, there is no standard value for DC distribution voltage level. However, IEC formed a new system Evaluation Group SEG 4 in November 2014, to focus on LVDC applications, distribution and safety regulations. So, you can see I have shown one graph in the bar chart form, where you can see that almost 12 volt of the voltage it share is more than 5 percent 48 volt, that is also common and its share is close to 15 percent and 380 volt that is also close to 15 percent and 1500 that is also close to 10 percent and 750 volt that is also about 5 percent. So, this 5 are the common voltage level used for any DC microgrid.

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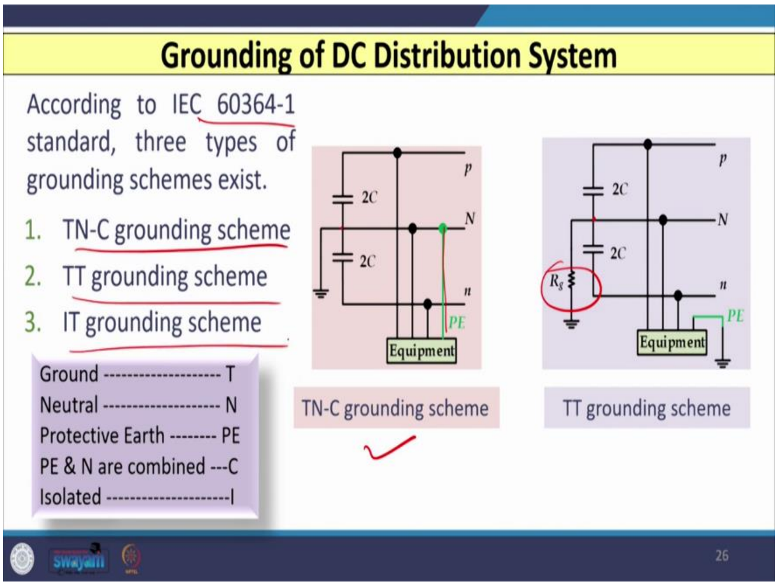

Now, let us see what is the grounding requirement of DC distribution system. So, according to IEC 60364-1 standard 3 types of grounding schemes exist for DC microgrid. The first is the TN-C grounding scheme as shown here. And the main thing is that in this scheme, this point is directly or solidly grounded and the neutral and protective earth of the equipment that is directly connected. The second type of scheme is the TT grounding scheme in which this point is grounded, but not solidly to some resistor and you can see the protective earth this of the equipment that is grounded separately instead of connecting with the neutral in the grounding scheme.

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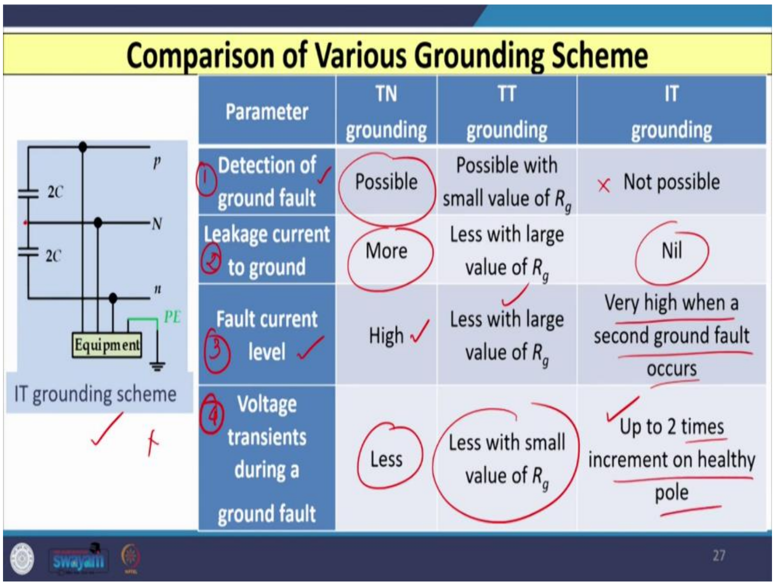

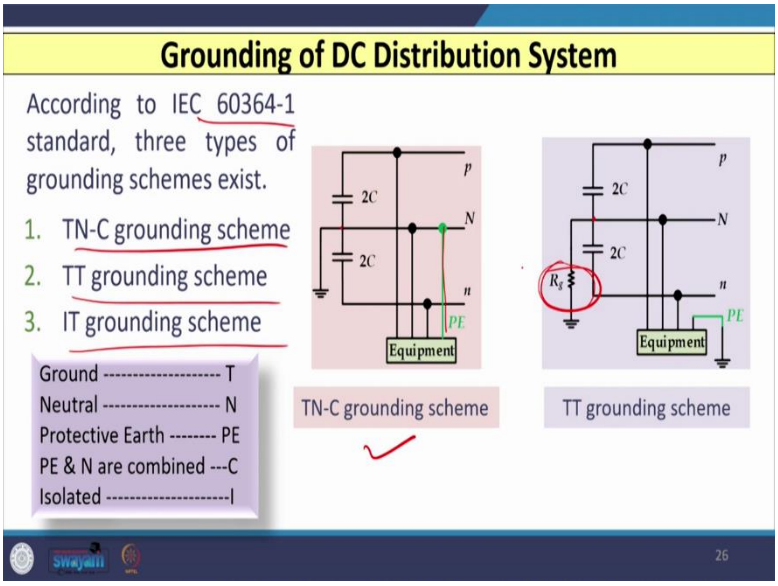

And the third type of scheme that is IT grounding scheme we can see that this point is isolated and protective equipment that is connected to the ground. So, here if I compare the TN, TT and

IT grounding scheme then detection of ground fault current is concerned that is possible for TN grounding scheme because it is solidly grounded, it is also possible for TT grounding scheme because, if I put the small value of this R_g, then that is also possible, but that is not possible for this scheme, because this point is not grounded.

The second parameter is the leakage current to ground. So, that is more in TN grounding scheme because it is solidly grounded, it is less with large value of Rg. So, if I put large value of Rg, then this leakage current is less and here there is no leakage current because it is isolated or open. The fault current level third parameter that is high for TN system, because it is solidly grounded, it is less with large value of Rg. So, if I put large value of Rg then the fault current level is less and here in this case for IT grounding if first ground fault is there, then no dangerous fault current level is there.

But if second ground fault occurs then magnitude of fault current is very high and the fourth parameter is the voltage transient during a ground fault. So, you can see for TN grounding it is less it is also less for TT grounding with small value of Rg, but in IT grounding as it is isolated. So, the healthy pole voltage is that becomes almost doubled. So, these are the comparison of 3 important grounding scheme used for the DC microgrid.

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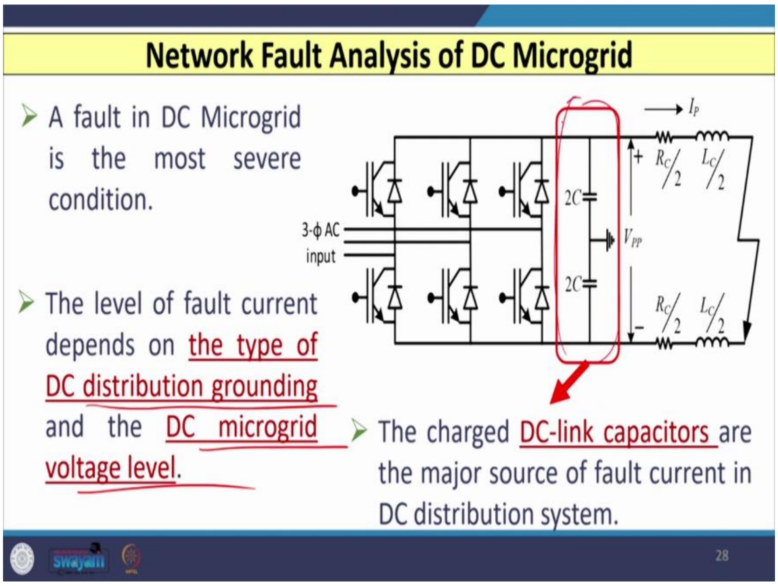

Now, if I consider the fault analysis condition in DC microgrid, then in a DC microgrid a fault whenever it occurs, it is a very critical issue because the level of fault current in DC microgrid that depends on type of DC distribution grounding which we have discussed 3 types and the

DC microgrid voltage level. So, whenever fault occurs the charge DC link capacitors this thing as shown here, this are the major source of fault current in DC distribution system.

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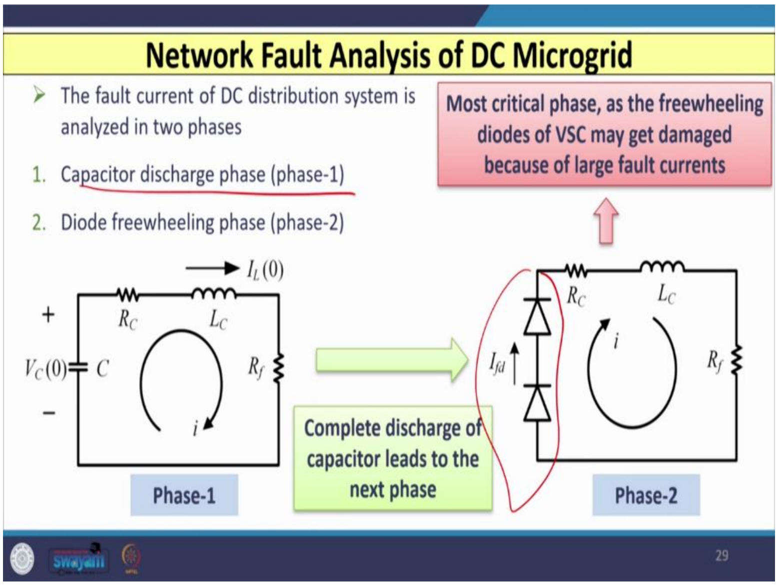

So, whenever the fault is going to occur in DC distribution system, then this can be analyzed in 2 phase, in phase one it is nothing but the capacitor discharge mode or phase where the this capacitor is going to discharge and current flows through this. And once the capacitor is completely discharged, then the freewheeling diode that will come in picture and this is the very critical case as the freewheeling diodes of the voltage source converter, they may get damaged because of the large value of fault current that flows through it. So, this is a very important issue, when we are dealing with the fault analysis in case of DC microgrid.

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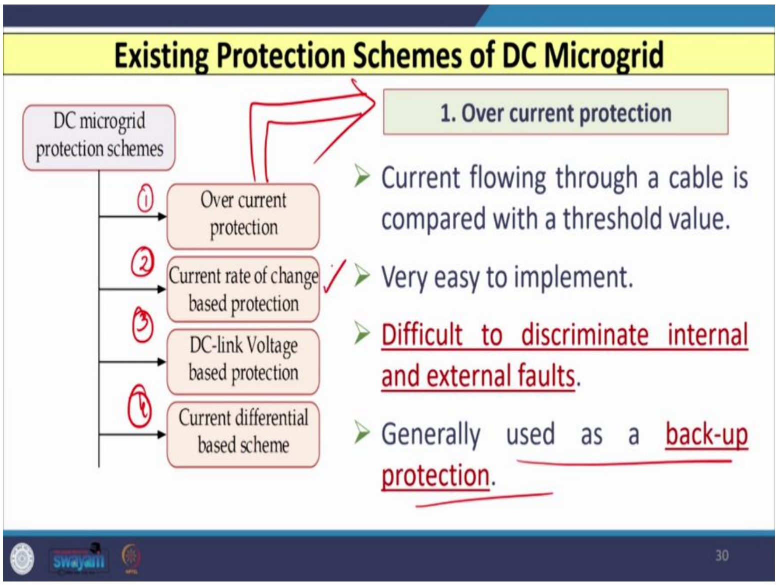

Now, let us see what are the existing protection schemes for DC microgrid. So, for DC microgrid 4 types of schemes are used and that is the overcurrent. So, first is the overcurrent protection scheme. So, the current flowing through a cable that is compared with some threshold or pickup or pluck setting, So, it is very easy to implement this scheme.

However, if I use this scheme, then it is very difficult to discriminate internal and external fault because the power flow is bi directional and generally this type of scheme is used as a backup protection, but as a primary protection, we do not use these because of the 2 main disadvantages first, very difficult to discriminate internal and external fault because of the bidirectional power flow and second we need instantaneous operation which cannot be possible using this type of protection scheme.

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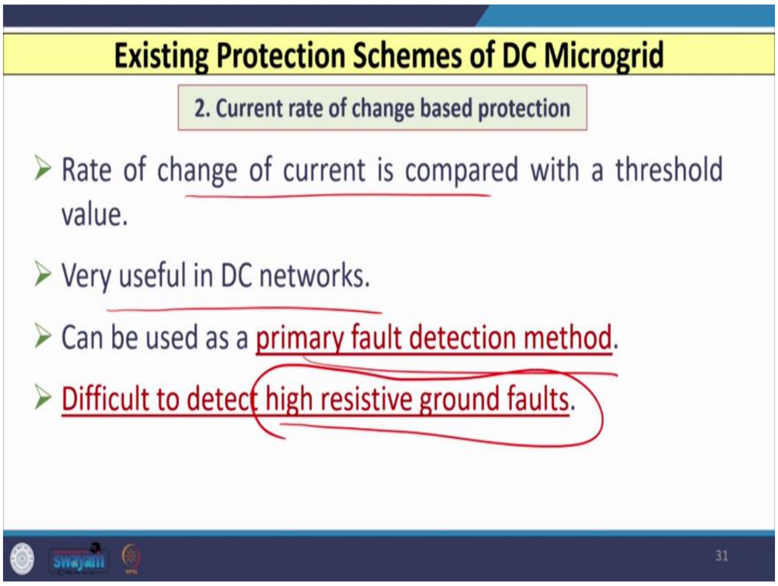

So, the second type of scheme is the current rate of change-based scheme. So, this scheme is based on rate of change of current and that value is compared with some threshold value. So, this type of scheme is very useful for DC network and it can be used as a primary fault detection method. However, it is very difficult to detect high resistive ground faults if I use rate of change of base protection scheme.

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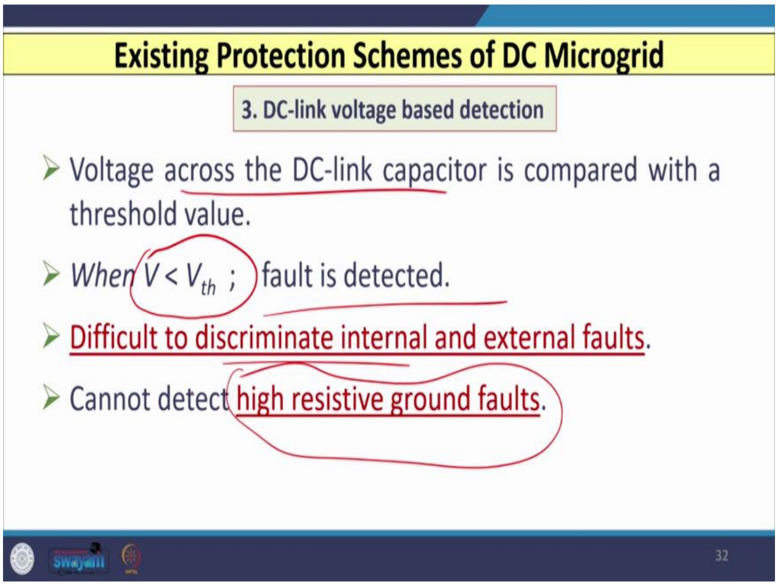

So, the third type of scheme that is DC link voltage-based detection scheme, in this scheme voltage across the DC link capacitor is compared with some threshold value. So, when V is less than V^{th} then the fault is detected otherwise it is some external condition or normal condition. However, it is difficult to discriminate between internal and external fault using this scheme and this scheme also faces difficulty in detecting high resistive ground faults.

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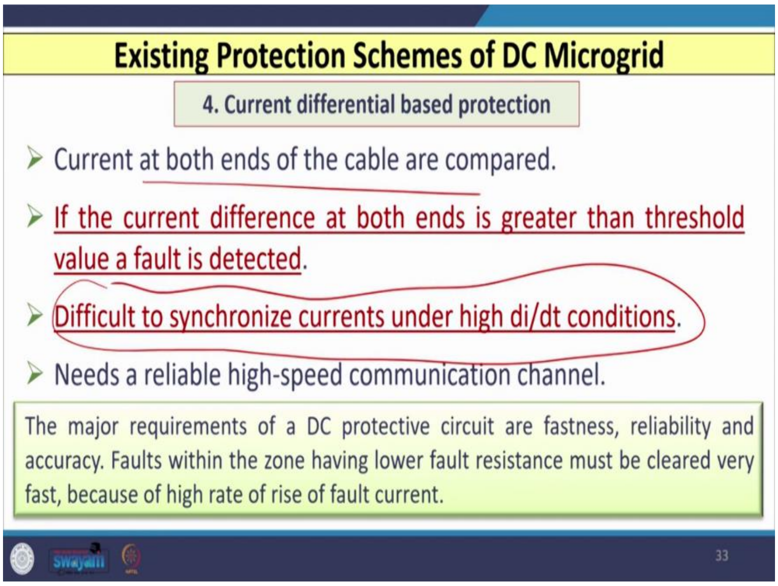

So, the fourth type of scheme that is known as current differential base protection scheme. So, in this scheme current at both ends of the cable are compared. So, you need remote as well as the local end data if the current difference at both ends is greater than the threshold value, then the fault is detected. Here for this scheme phase a difficulty to synchronize currents under high di/dt conditions and this scheme needs a high-speed communication channel.

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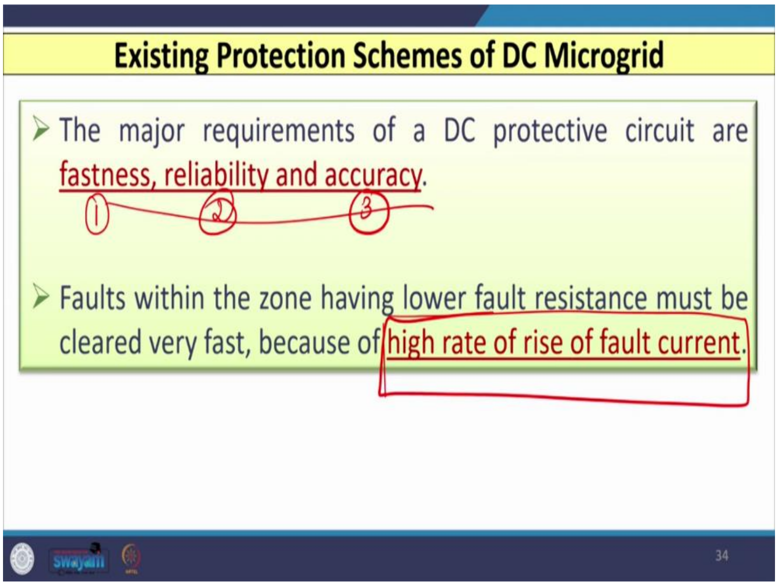

So, we can say that the major requirements for any DC microgrid if I consider protection wise then the protective scheme used for DC microgrid, it has 3 important characteristic that is one is the fastness, second is the reliability and third is the accuracy. So, faults within the zone having lower fault resistance must be cleared very fast, because of high rate of rise of fault current. So, this type of fault that should be cleared instantaneously.

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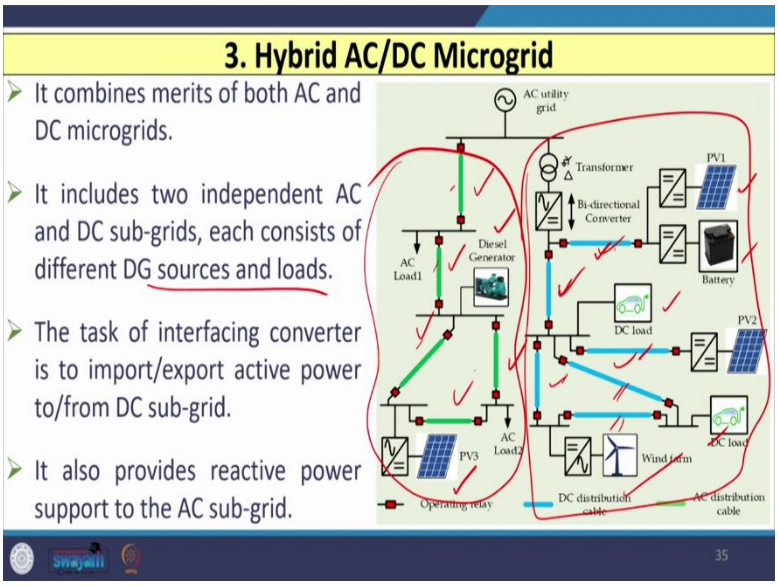

Now, let us see the third type of microgrid that is hybrid AC DC microgrid. So, hybrid AC DC microgrid is a combination of both AC microgrid and DC microgrid. So, you can see that this is the structure of hybrid AC DC microgrid and you can see there both AC and DC are shown here. So, you can see that this the scheme with the green color that I have shown here, these are your AC microgrid and all this blue color they are the DC microgrid systems.

So, hybrid AC DC microgrid includes 2 independent AC and DC sub grid. So, 2 AC sub grids, 2 DC sub grids and each sub grid consists of different distributed energy resources and loads. So, if I consider this system when you can see that we have a photovoltaic based generators and diesel generators are there with several AC distribution feeders.

Similarly, if I consider the DC microgrid, then it has PV battery or maybe wind farm based renewable energy sources or distributed energy resources with several loads are there which are connected with the DC distribution. So, the task of interfacing converter is to import or export active power to the DC sub grid or from the DC sub grid and it also provides reactive power support to the AC sub grid. So, that is why hybrid AC DC microgrid is preferred compared to the separate AC or DC microgrid.

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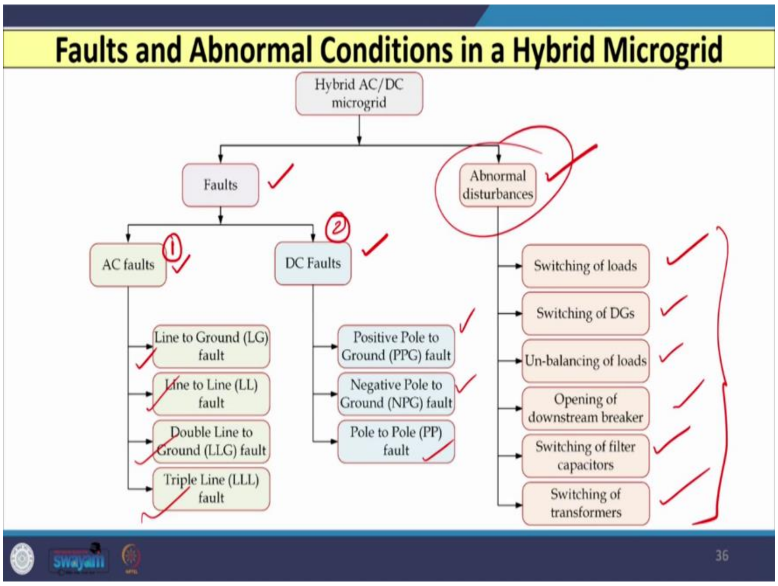

Now, if I consider faults or abnormal conditions which is going to occur in a hybrid AC DC microgrid, then faults and abnormal conditions are classified as in faults, 2 types of faults are possible AC faults and DC faults. So, in AC faults we have the line to ground fault, line to line fault, double line to ground fault and triple line faults are possible, where in DC faults we have positive pole to ground so PPG fault, negative pole to ground so NPG fault and pole to pole fault 3 faults are possible.

Whereas, in case of abnormal disturbances, it can be because of switching of loads, it can be due to switching of distributed energy resources, it can be because of the unbalancing of loads or opening of downstream circuit breakers maybe because of switching of filter capacitors or switching of transformers. So, because of any of this condition or even any other abnormal disturbances may occur, but keep in mind this are not a fault and the protective device should not operate in this situation.

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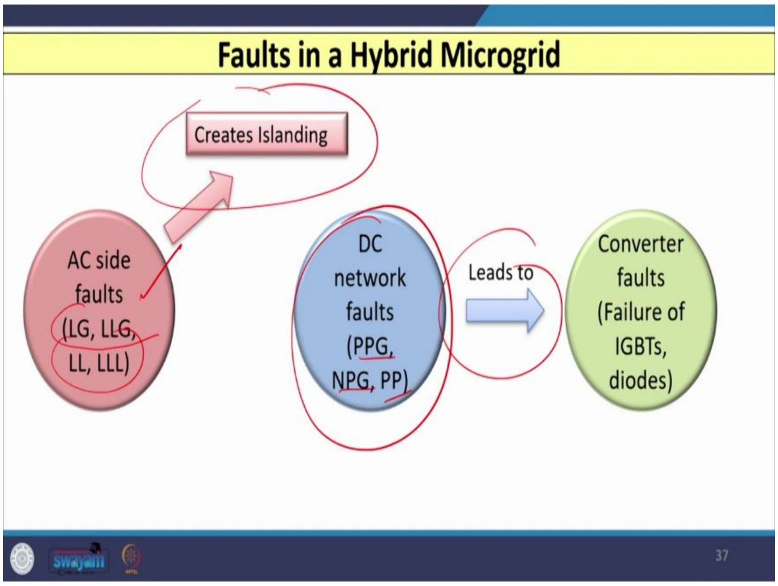

So, if I consider faults in a hybrid AC DC microgrid, then AC faults that creates islanding. So, it can be because of LG, LLG, LL or LLL fault, which are responsible for islanding situation that we need to avoid any if it is there, we need to detect it. The second is the DC network faults maybe because of positive pole to ground negative pole to ground and pole to pole. So, that is going to lead to converter faults, maybe failure of IGBTs or diodes. So, that also we need to detect as early as possible.

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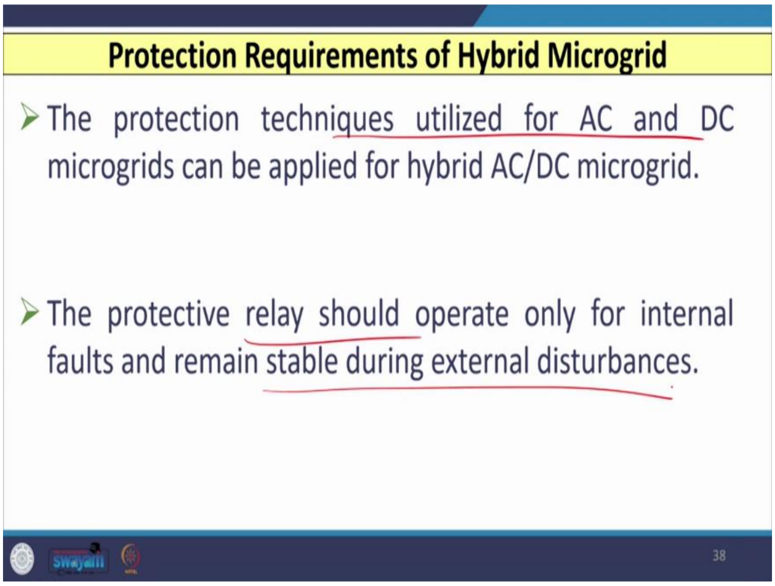

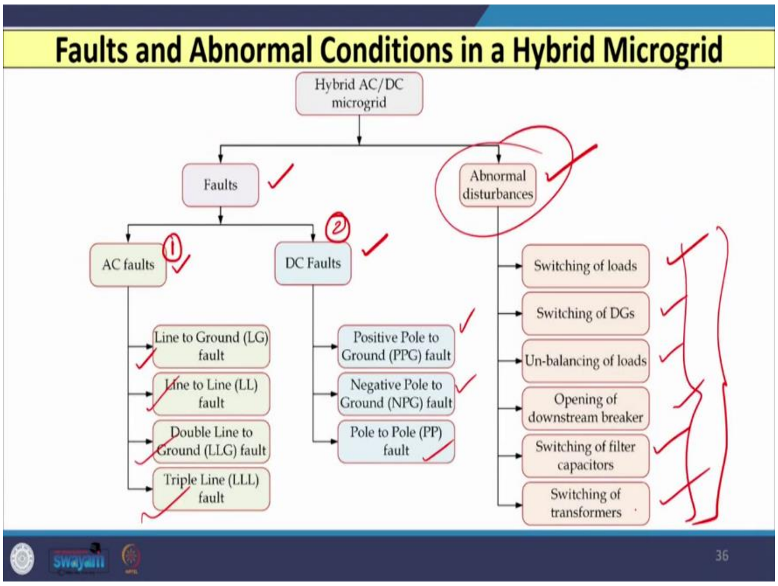

So, protection requirements of hybrid AC DC microgrid if we consider than protection techniques utilized for AC and DC microgrids can be applied to hybrid AC DC microgrid. The protective relay should operate only for internal faults and remain stable for any external disturbances as we have discussed earlier. So, any of this disturbance relay should not operate.

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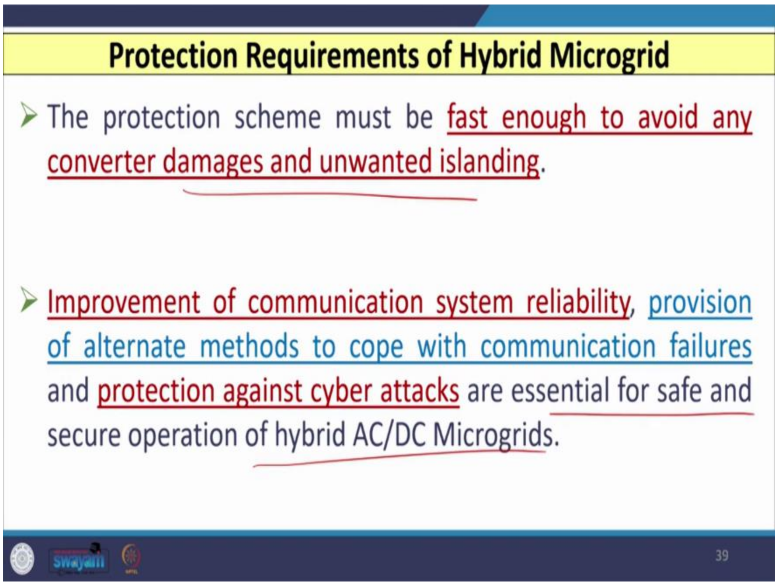

The protection scheme must be fast enough to avoid any converter damages and unwanted islanding. Improvement of communication system reliability, provision of alternate methods to cope with communication failures and protection against cyber-attacks these three are essential requirement for safe and secure operation of hybrid AC DC microgrids.

So, in this lecture we started our discussion with AC microgrid, we have seen that what is the structure of AC microgrid and what are the core issues faced by AC microgrid and to tackle those issues four different type of schemes are used that we have discussed.

Then we have discussed DC microgrid, we have seen the structure of DC microgrid and then we have seen that different 4 types of schemes are used and we have also discussed the voltage levels used for DC microgrid. Along with that we have discussed that what are the various schemes or protective schemes used for DC microgrid.

Along with that three different types of grounding system and then finally we have discussed about the hybrid AC DC microgrid. And we have discussed the faults and abnormal disturbances which are going to occur and relay should not operate in case of disturbances it operates only in case of fault. Thank you.