Power System Protection and Switchgear
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Lecture 33
Protection against Transients and Surges along with System Response to Severe Upsets II

So, let us discuss the our discussion which we were already discussed in the earlier class and that is related to protection against transient and surges.

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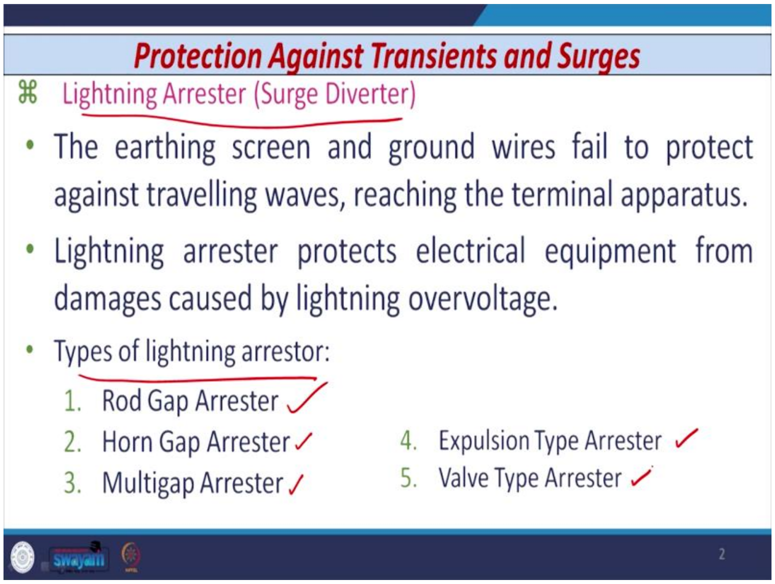

So, as we have discussed that there are several equipment use for protection against surges and transients, we started with the shielding or the earthing screen, then second we have discussed the main thing that is ground wire, the third we have discussed the surge diverter and the fourth one that is known as the lightning arrester. Sometimes it is also known as the surge diverter.

The earthing screen and the ground wires which are used for protection against surges, but this they are not capable to provide the protection against traveling waves which are going to reach the terminal apparatus. So, lightning arrester protects electrical equipment from the damages caused by lightning over voltages as well as some switching surges also.

So, let us see what are the types of lightning arrester. So, there are five types of lightning arrester. The first that is known as the rod gap lightning arrester; the second is known as the horn gap arrestor; the third that is known as multigap arrester; the fourth that is known as expulsion type arrester; and the fifth that is known as the valve type arrester. So let us discuss each and every lightning arrester one by one.

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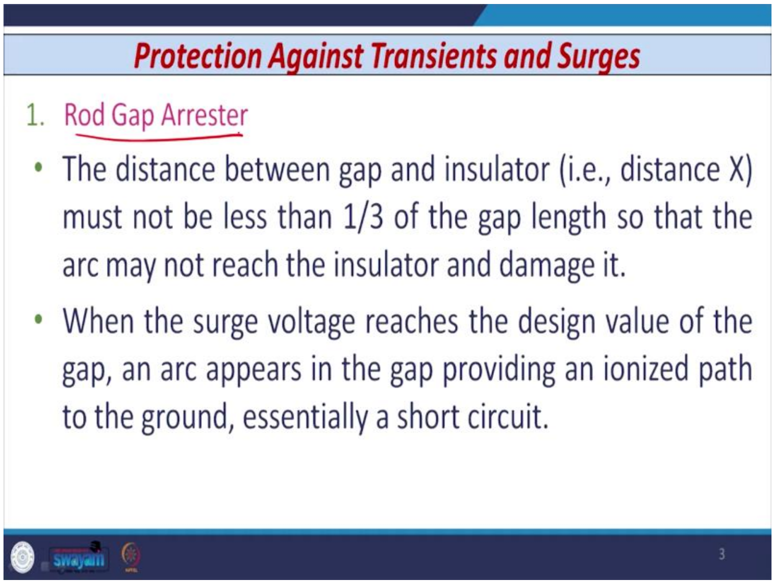

So the first type of arrestor that is known as the rod gap arrestor. So, in rod gap arrester, the distance between the gap and the insulator, let us say some X distance that must not be less than one-third of the gap length, otherwise, the there are fair chances of the arcing. So, if we maintain this distance, this ratio, then the arc may not reach the insulator and the insulators are not going to damage. Whenever the surge voltage reaches the design value of the gap, the arc appears in the gap providing an ionized path to the ground, specially a short circuit.

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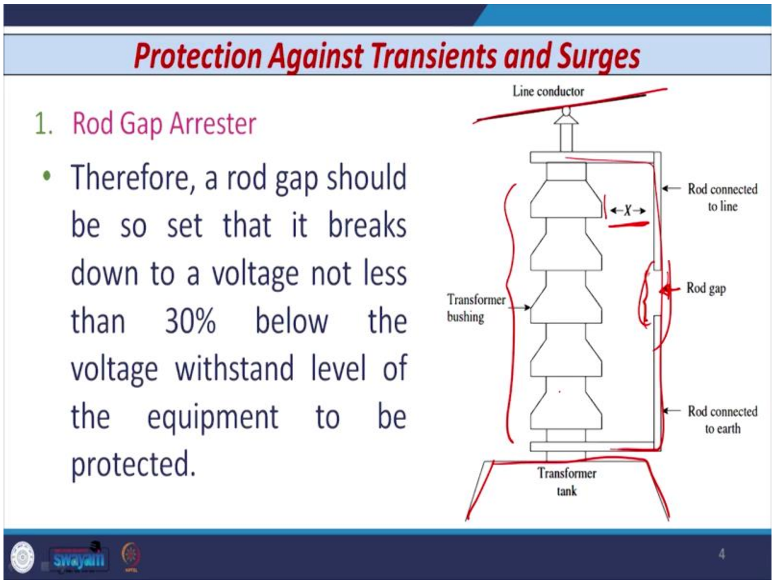

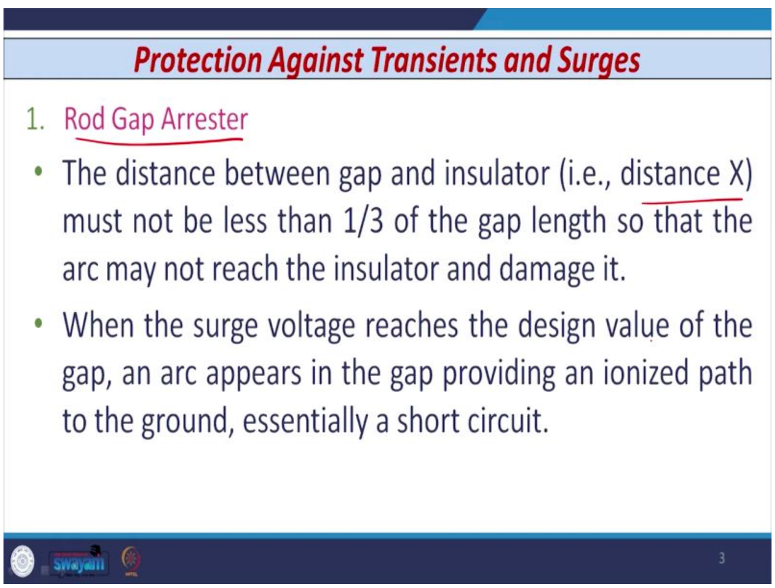

So, you can see here, I have shown the figure of the rod gap arrester. So, these are the transformer bushings and this is the transformer tank and on upper side you have the line conductor with insulators are there. So with this insulator, there is a one rod connected to the line it is known as line rod.

And with this earth, you can see there is a rod connected to the earth that is the earth rod. And there is a gap between these two road that is known as the road gap. And I am talking about this distance that is from the insulator to the rod that is the X distance, as I told you here this distance, should not be less than one-third of the gap length that is this length that is the rod gas length. So, therefore, a rod gap should be so set that it breaks down to a voltage lot less than the 30 percent below the voltage withstand level of the equipment to be protected.

Whenever there is an arc across this. So, as I told you earlier, that when the surge voltage reaches the design value say suppose some X value or Y value, then the arc appears in the gap providing an ionized path to the ground in particularly in case of short circuit. So arc appear across this and that is going to provide the path and this equipment or the busing that is protected.

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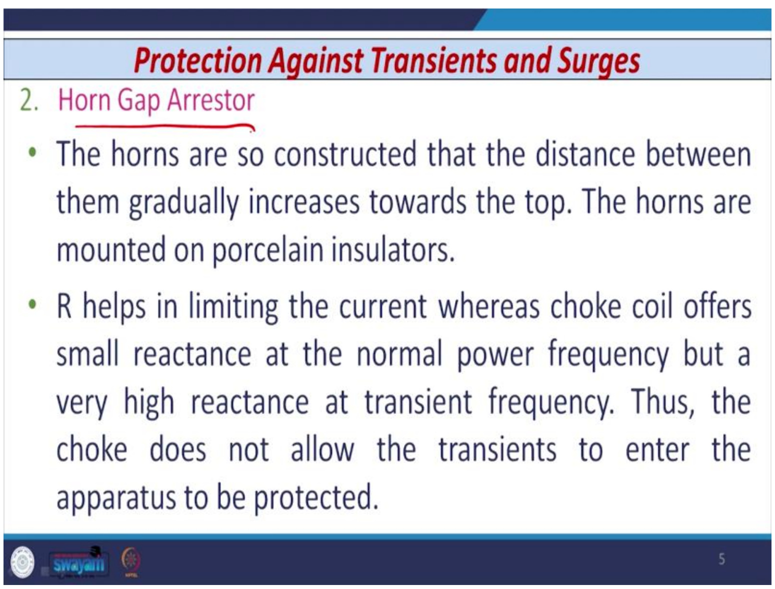

The second type of the arrester that is known as the horn gap arrester. So the name itself suggests contains the horns and these horns are so constructed that the distance between the horns that is gradually increases towards the top. So as you move from the bottom to the top, the distance between these that is going to increases. The horns are usually mounted on the porcelain insulators.

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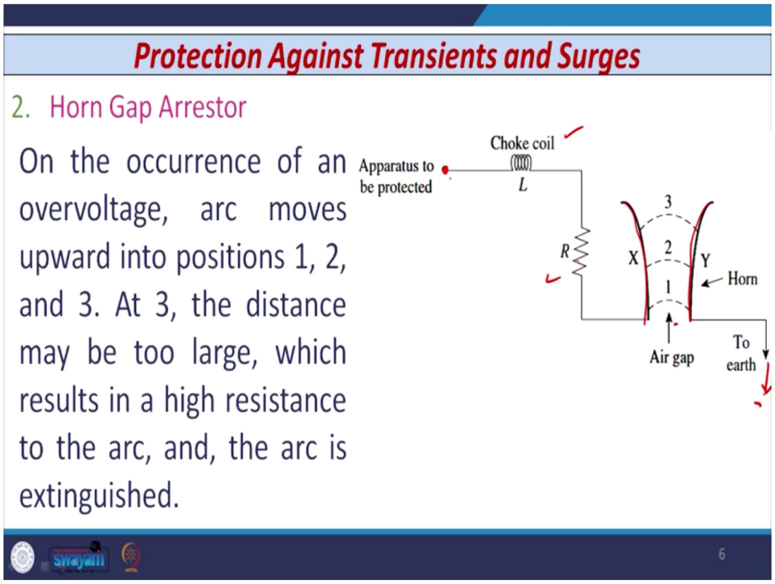

So, if I consider the circuitry of the horn gap, there you can see that apparatus to be protected that is connected here, that is the point, and this is the earth point. And between this, this point and this earth point, there is an horn. So this is your horn gap and you can see that as you move from this point to this point from 1, 2, 3, I have labeled three points, so as you move from point number 1 to point number 3, the distance that increases. Along with that one choke coil and one resistor R that is also connected.

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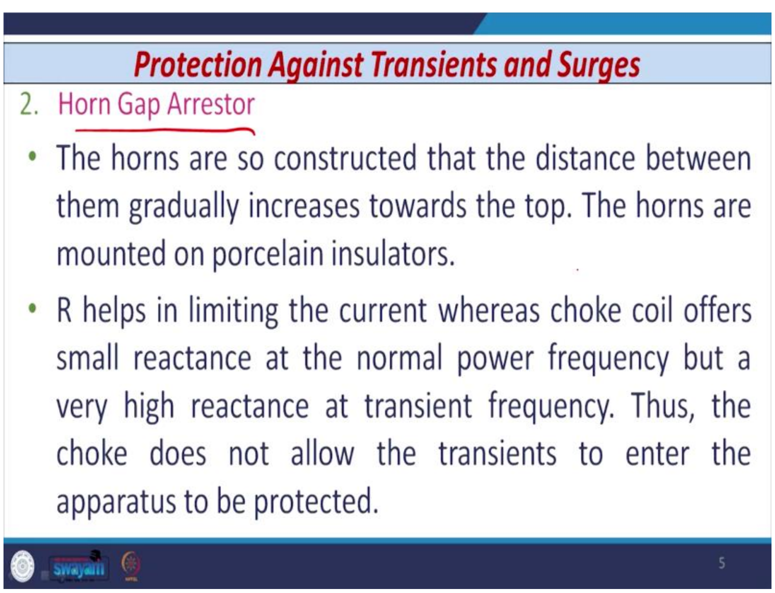

So, the resistor R that acts as a current limiting resistor, which is going to limit the magnitude of current, whereas the choke coil offers the small reactance at the normal power frequency, but it offers the or it provides very high reactance at transient frequency. Basically, the choke coil does not allow the transients to enter the apparatus on for the apparatus to be protected.

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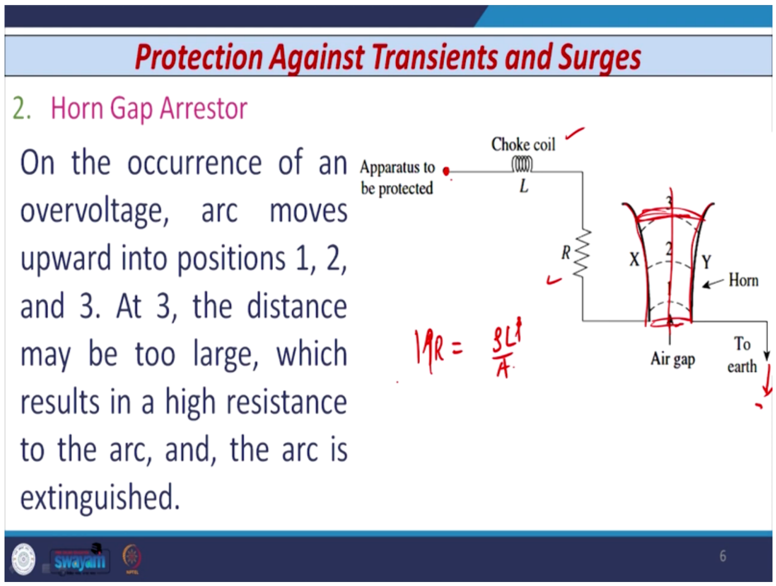

So, on the occurrence of an overvoltage, the arc move towards the upper position from point number 1 to point number 2 to point number 3. So, whenever it reaches at point number 3, the distance that is very high or they are very large, such that that results in high resistance of the arc, so arc that is which is going to be formed here that moves upward and whenever it reaches here, basically arc is going to be lengthened and we know that R that is equal to rho L by A.

So as we increase the length of the arc, then the resistance of the arc increases and hence the possibility of the sustainability of the arc that reduces and arc can be easily extinguished.

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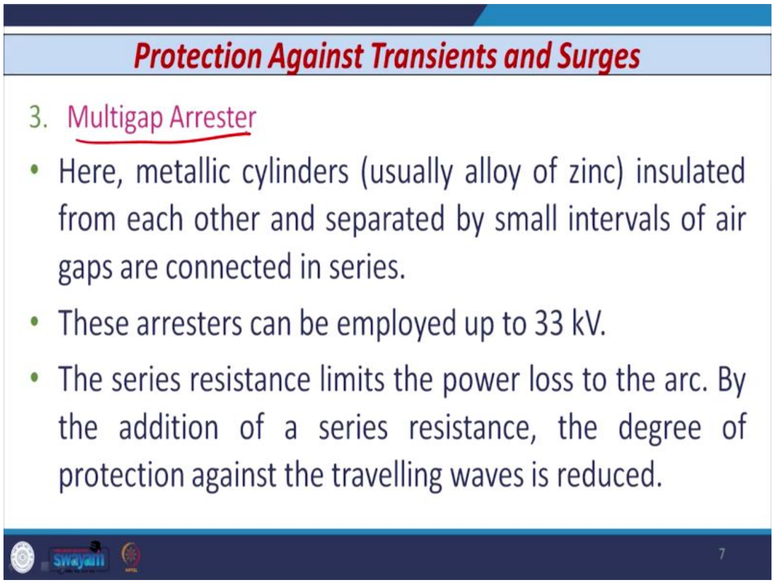

The third type of arrestor that is known as the multigap arrestor. So, as the name suggests, different gaps are provided. So, here are the metallic cylinders, usually made up of zinc, that is insulated from each other and separated by small intervals of air gaps that is corrected normally in series.

These type of arresters that can be used or employed up to only 33 kV voltage level. The series resistance limits the power loss to the arc and by the addition of the series resistance, the degree of protection against traveling wave that can be reduced.

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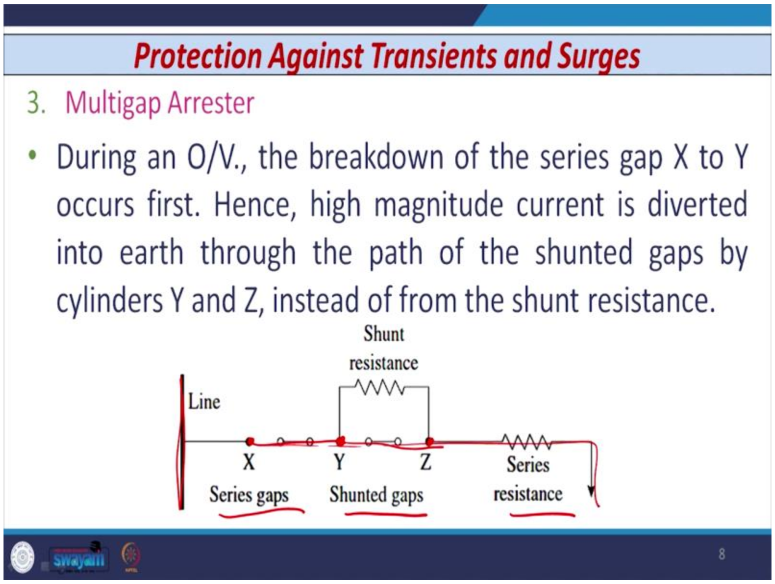

So, as I told you, multiple gaps are provided. So, you can see that in this figure, I have shown the multigap arrestor, where the series gap, shunt gap and series resistance are provided. So, this is the line. So, there is a gap X, there is the another gap Y and there is the another gap Z.

So during the overvoltages, wherever overvoltage comes, the breakdown of the series gap X to Y occurs first. So this breakdown occurs first. Hence, high magnitude of current that is diverted to the earth through the path of the shunted gaps by the cylinders Y to Z, so again this gap that is going to occurs and whole current that is diverted like this instead of going to the shunt resistor.

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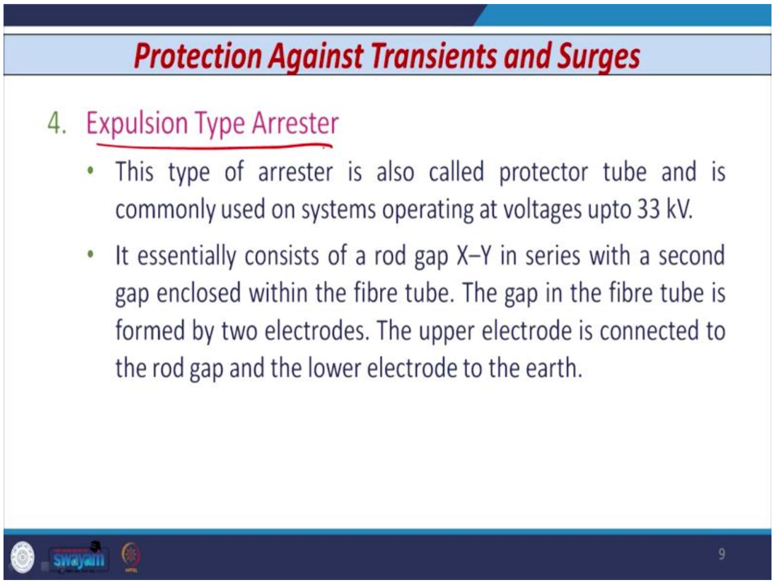

The fourth type of lightning arrester that is known as the expulsion type lightning arrester. So, this type of arrestor is also called the protector tube and it is commonly used for the system operating at voltage up to 33 kV. So it essentially consists of a rod gap X-Y in series with a second gap enclosed with some fiber tube and the gap in the fiber tube is formed by the two electrodes. The upper electrode is connected to the rod gap and the lower electrode that is connected to the earth.

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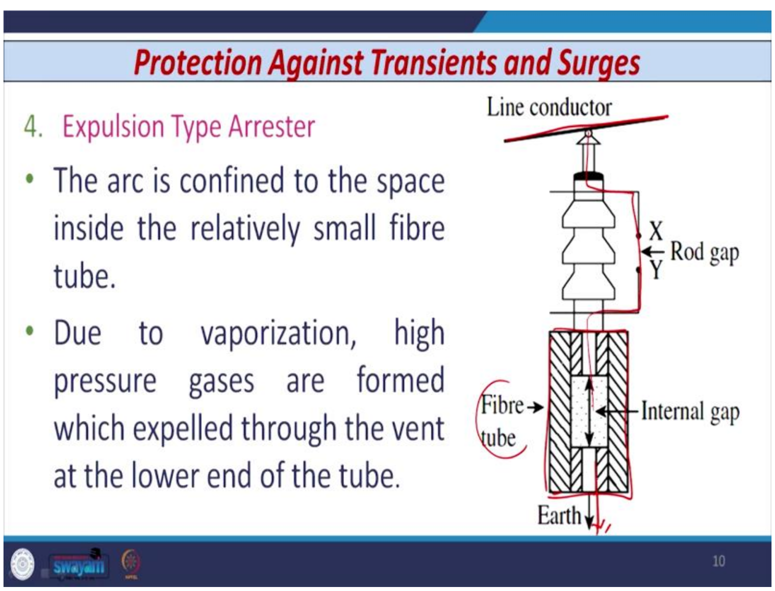

So, you can see I have shown the diagram where the line conductor is here and you have the rod gap X-Y. So, upper electrode is connected here, lower is connected here, and again there is a fiber tube here. You can see this is the fiber tube. Bottom of this tube that is connected to the earth. And there is an internal gap in this tube.

So, the arc that is confined to the space inside the relatively small fiber tube, so due to vaporization, high pressure gases are formed which that is going to be expelled through the vent at the lower end of the tube. So you can see here there is a vent is there. So because of vaporization, whenever arc is formed, several gases are formed and those gases are again passed to the vent, and hence, that arc can be easily quenched. So, basically, it moves like this.

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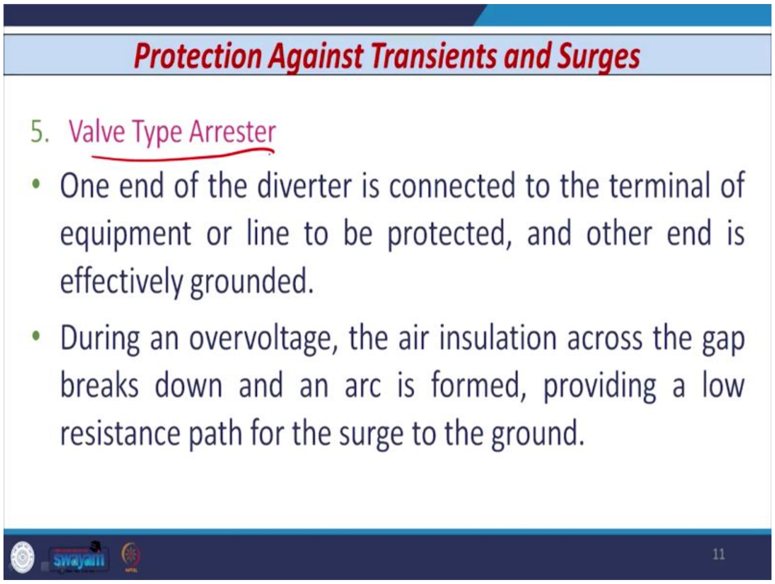

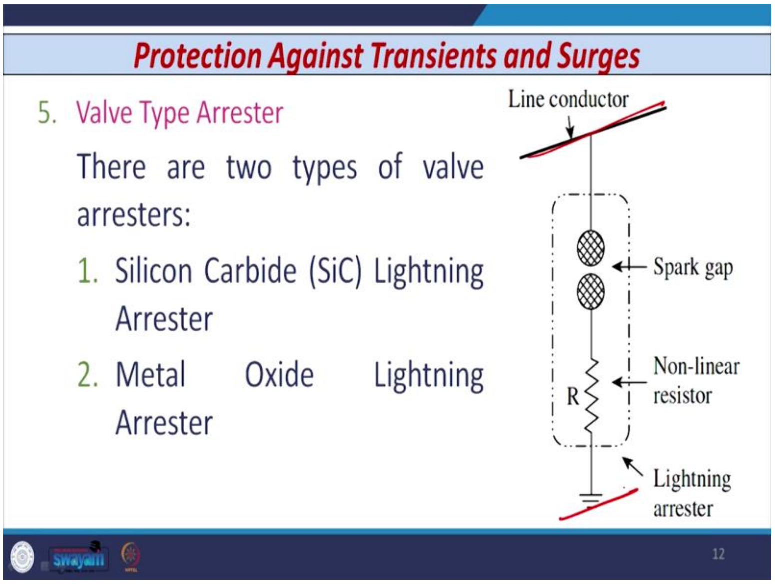

The next type of arrestor that is known as valve type arrestor. So, one end of the diverter here in this case that is connected to the terminal of the equipment or the line to be protected, whereas the other end of the valve type arrestor that is effectively grounded. So one end is connected to the line or the equipment to be protected, and one end that is connected to the ground.

During an overvoltage, the air insulation across the gap breaks down and an arc is formed, providing a low resistance path for the surge to the ground. Whenever the overvoltage occurs, the air insulation across the gap breaks down, so across these gaps breaks down, which is going to again provide so whole of the energy that is dissipated like this to the earth.

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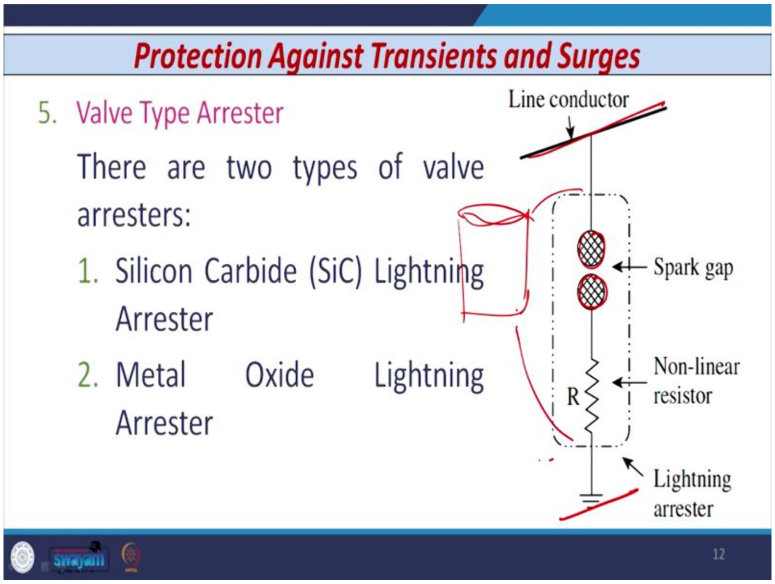

So, you can see here in this figure, there is a spark gap have provided, so this gap that is going to break. You have a non-linear resistor is also there, which is connected in series with the spark gap and which is connected to the ground. So, basically this whole lightning arrester that is of the cylinder shape like this, dumb shape, and though that is connected here.

So basically there are two types of valve arresters one is known as silicon carbide lightning arrester and the other is known as metal oxide lightning arrester, it is basically made up of ZnO that is the zinc oxide.

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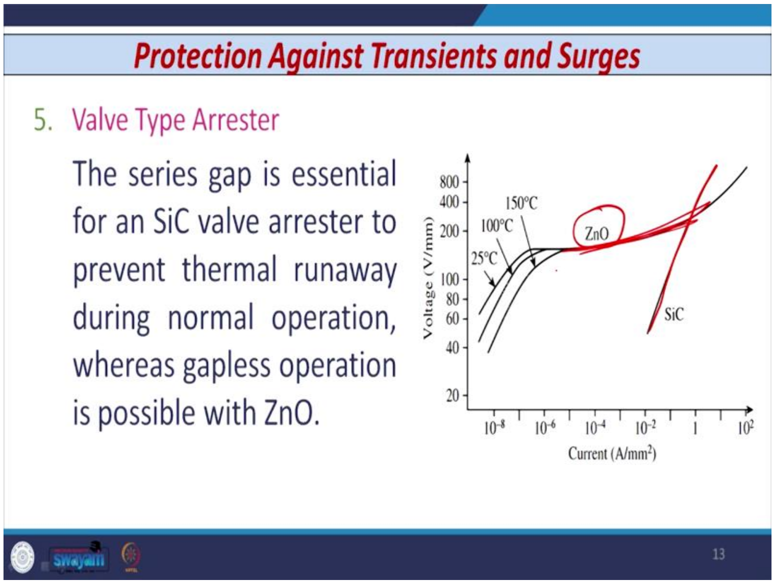

So, if I consider the characteristic of this silicon carbide and the ZnO type the arrestor, then you can see that I have shown the voltage that is volt per millimeter versus the current in ampere per mm square that is shown for the both type of arresters. So, you can see the silicon carbide arrester characteristic is like this that means at particular point of time of current as you move increase the current, the voltage that also increases.

Whereas, if you compare the ZnO type of lightning arrester, then at different degree its characteristics is shown, but, however, you can see that in this region even though you increase the current, the voltage that is almost remains constant. So, this is the reason in actual field or practical field, the ZnO type lightning arrester that is widely used.

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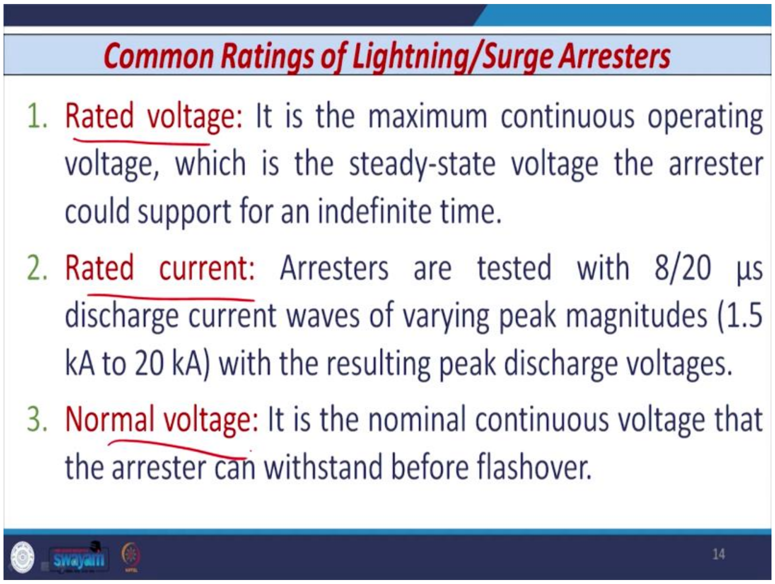

Now, let us see what are the some common ratings of lightning or surge arresters. So, whenever you want to procure the lightning arrester, few things need to be defined. The first thing that is known as the rated voltage of the lightning arrester. So, the rated voltage is the maximum continuous operating voltage, which is basically the steady state voltage, the arrester could support for an indefinite period of time.

So, that is known as the rated voltage. The next is the rated current that is the arresters are usually tested with 8 by 20 microsecond discharge current waves with varying peak magnitudes from 1.5 kilo ampere to 20 kilo ampere with the resulting peak discharge voltages. The normal voltage, third, it is the nominal continuous voltage that the arrester can withstand before flashover occurs.

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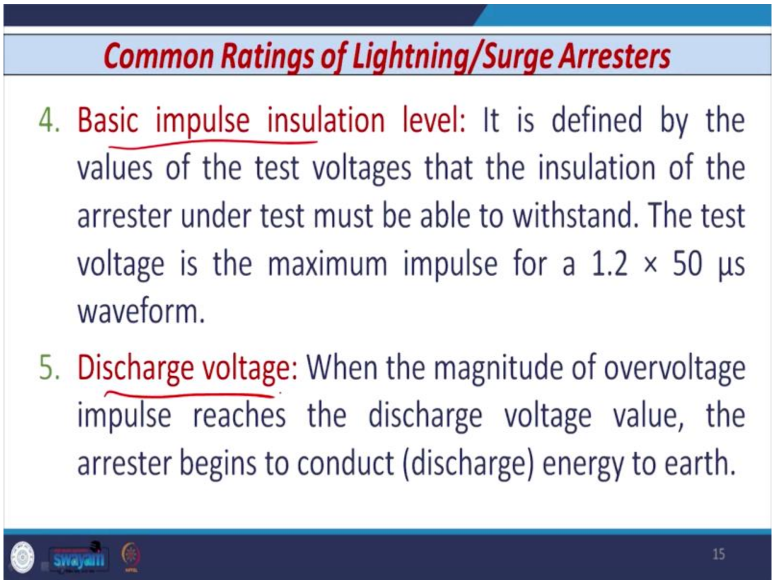

The fifth that is the basic impulse insulation level. So, basic impulse insulation level is defined by the values of the test voltage that the insulation of the arrester under test must be able to withstand. So whenever you test the arrester, the insulation of the arrester is capable to withstand up to how much level of voltage that is known as the basic impulse insulation level.

The test voltage that is the maximum impulse for a 1.2 to 50 microsecond waveform. The next is the discharge voltage. So, when the magnitude of overvoltage impulse reaches the discharge voltage value, the arrester begins to conduct, that means it discharges the energy to the earth. So that voltage is known as the discharge voltage.

So, with this background let us consider the another topic that is known as the what is the behavior, whenever such type of surges and transient comes in the power system, then what is the behavior of power system in this condition.

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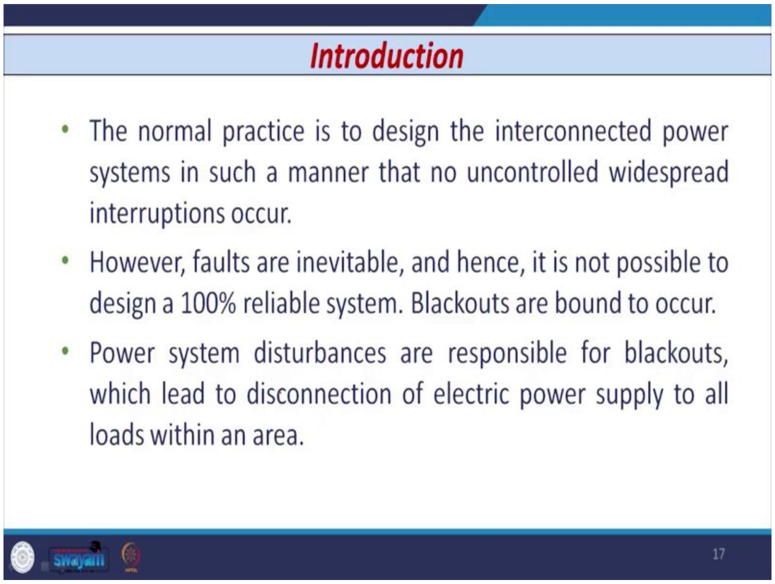

So, we know that, the normal practice is to design the interconnected power system or the whole network in such a manner that the no uncontrolled widespread interruption occur, so basically no blackout occurs. However, faults are inevitable, transient and surges are also going to occur and hence it is not possible to design 100 percent reliable system. So that means blackouts are bound to occur. Power System disturbances are responsible for blackouts, which leads to the disconnection of electric power supply to all loads within a particular area or to a larger area.

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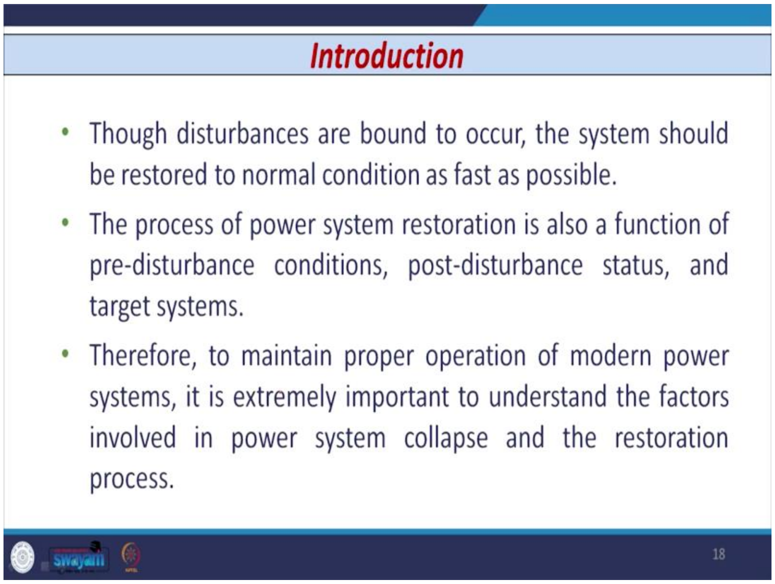

Though disturbances are bound to occur, the system should be capable to restore to the normal condition as fast as possible. The process of power system restoration is also a function of the pre-disturbance conditions, post disturbance status and the target systems. Therefore, to maintain proper operation of modern power systems, it is extremely important to understand the factors involved in power system collapse and the restoration process.

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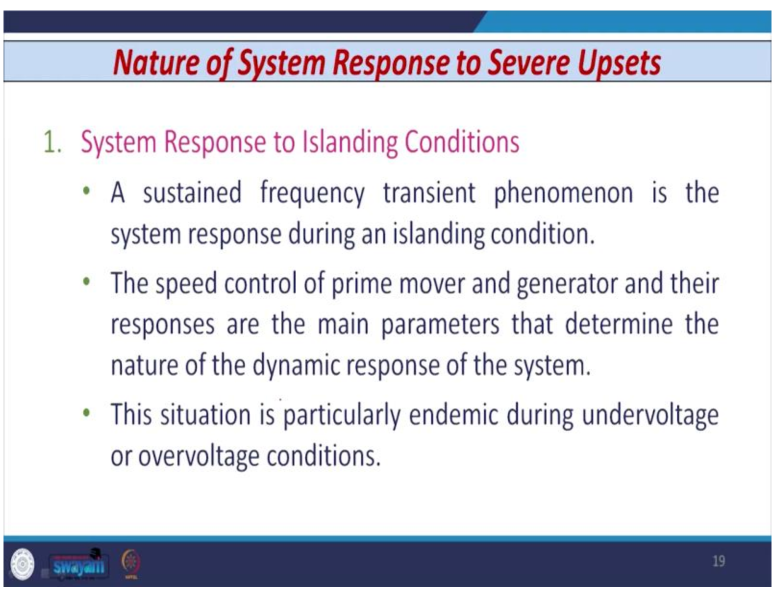

So, let us consider the -- what is the nature of system response in whenever the severe upset or blackout occurs. The system response to islanding conditions. So, this is one of the important condition which occurs in actual or practical system. So, a sustained frequency transient phenomenon is the system response during islanding condition, we will see what is the meaning of islanding.

Whenever such type of condition occurs, the speed control of prime mover and the generator and their responses are the main parameters that determine the nature of the dynamic response of the system or transient response of the system. The situation is particularly endemic during undervoltage or overvoltage conditions.

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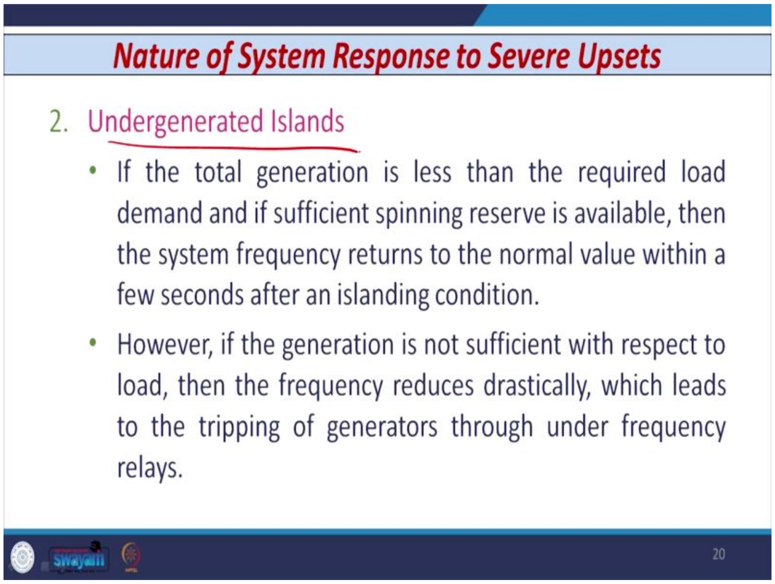

The second phenomenon that is known as undergenerated islands. If the total generation is less than the required load demand and if sufficient spinning reserve that is available, then the system frequency returns to normal value within a few seconds after certain phenomenon like islanding condition occurs. However, if the generation is not sufficient with respect to load, then the frequency reduces drastically, which in turn leads to the tripping of generators through under frequency relays.

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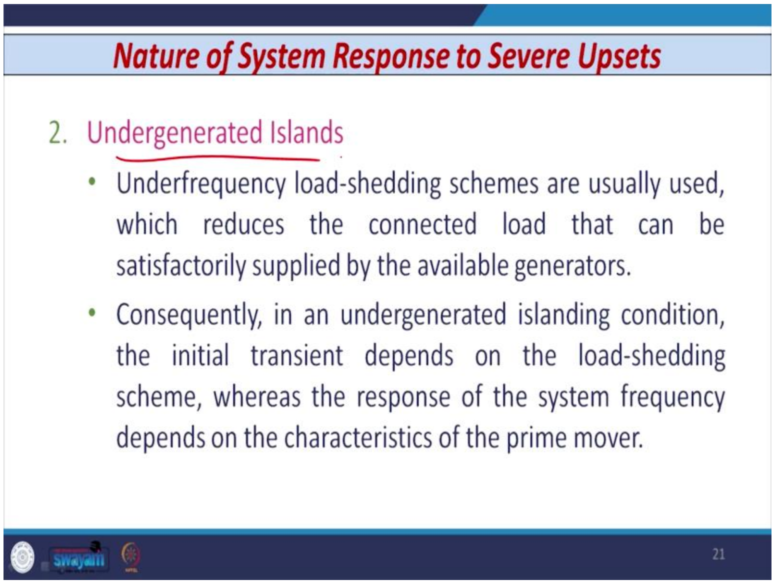

The under frequency islands, if I consider, then again the under frequency load-shedding schemes are usually used which reduces the connected load that can be satisfactorily supplied by the whatever is the available generators. So, consequently, in an under generated islanding condition, the initial transient depends on the load-shedding scheme, whereas the response of the system frequency depends on the characteristic of the prime mover.

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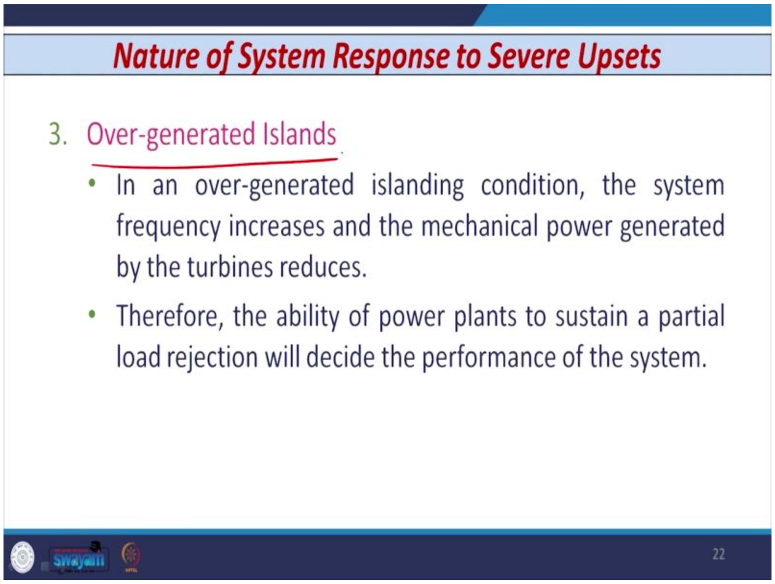

The next phenomenon that is known as over-generated islands. So, in an over-generated islanding condition, the system frequency increases and the mechanical power generated by the turbine reduces. Therefore, the ability of power plants to sustain a partial load rejection that will decide the performance of the system.

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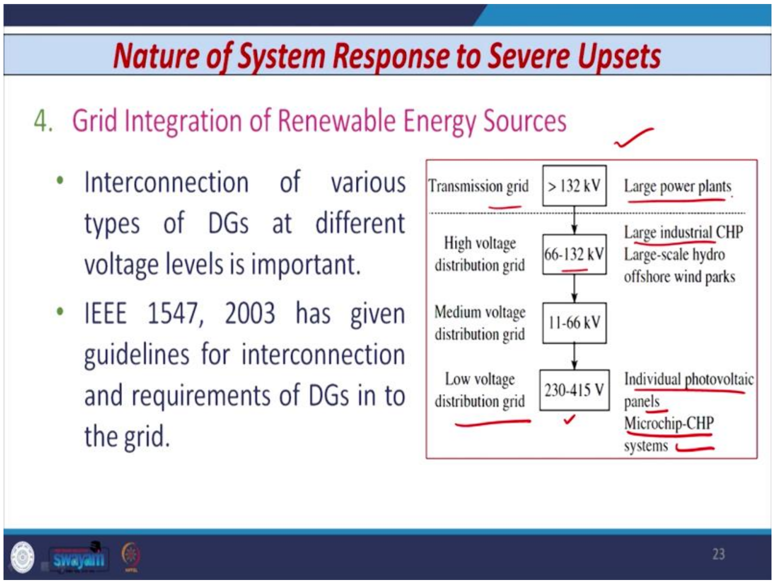

Now, if I consider the present scenario, then we know that the integration of renewable energy sources that is increasing day by day and this penetration of renewable energy sources maybe photovoltaic or wind or some other that is entering the grid, conventional grid, maybe at distribution level or medium voltage level or transmission level. So, integration of various types of DGs at different voltage levels that is shown here in this diagram, so you can see that at low voltage distribution grid that is 230 and 415 volt, the individual photovoltaic panels that are injected the power.

You can also use some microchip or combined heat power system. If you go maybe at high voltage distribution grid at 66 to 132 kV, then large industrial combined heat power, large scale hydro offshore wind parks through which the renewable powers that is injected into the system. And at transmission level, of course, the large power plants that is also there, which are going to inject the energy into the system.

However, whenever such type of injection takes place from the renewable energy sources, there is a standard known as IEEE 1547 standard designed in 2003 again amended in 2011 and 15 that has given some guidelines for interaction and requirements of DGs into this.

So, whenever you connect a distributed generators or distributed energy resources like photovoltaic, wind, offshore wind into the system, grid, then there are certain guidelines which need to be followed. Those guidelines are known as interaction and requirements of interconnection of distributed energy resources with the grid and those guidelines are given in this IEEE 1547 standards.

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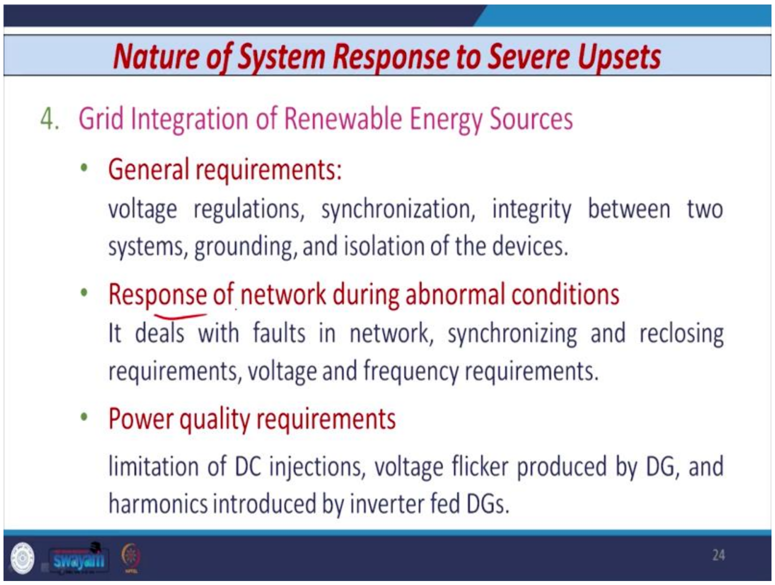

So, let us see what are those guidelines briefly. So, the general requirements are voltage regulations need to be followed when you inject, so voltages are same; proper synchronization procedure need to be followed; integrity between the two systems need to be maintained; grounding systems are also evaluated; and isolation of the devices that also play an important role.

The next point that is the response of network during abnormal conditions. So this deals with the fault in network, synchronizing and reclosing requirements, and voltage and frequency requirements. And of course, there are some power quality requirements also, limitation of DC injection, voltage flicker produced by distributed energy resources, and harmonics injected by inverter fed DG like distributed generators used with the photovoltaic system.

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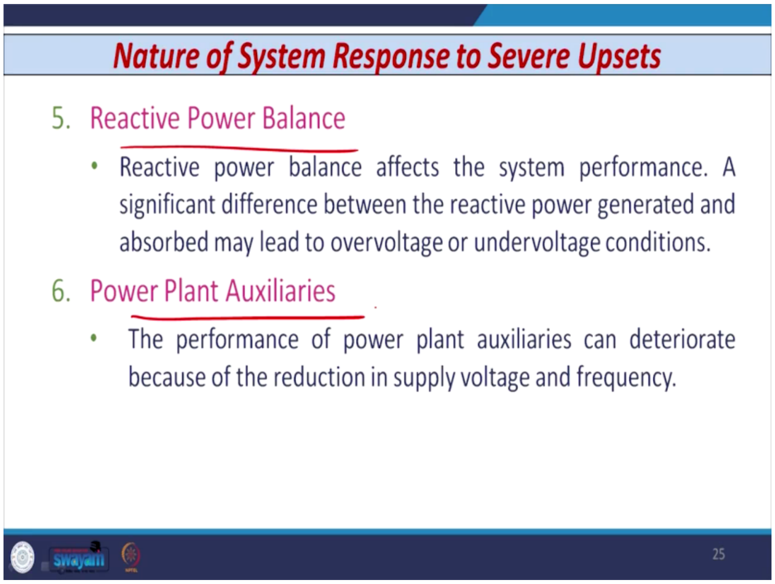

Of course, we do have the some reactive power balance requirement. So, reactive power balance affects the system performance. A significant difference between the reactive power generated and the reactive power absorbed may lead to the overvoltage and undervoltage conditions. And of course, some power plant auxiliaries are also there. So, the performance of power plant auxiliaries can deteriorate because of the reduction in supply voltage or frequency. So that needs to be considered.

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And the last point that is the power system restoration. So, the restoration of whole interconnected power system network whenever some blackout occurs after that restoration process starts. So, the restoration of the whole network includes several steps such as restoration of generating units and loads, balance between generation and load, and resynchronization of islands and other equipment.

So, the restoration process can be speeded up maybe adopting several methods, such as drawing power from the captive power plants, maybe like diesel generator set or gas based power plants.

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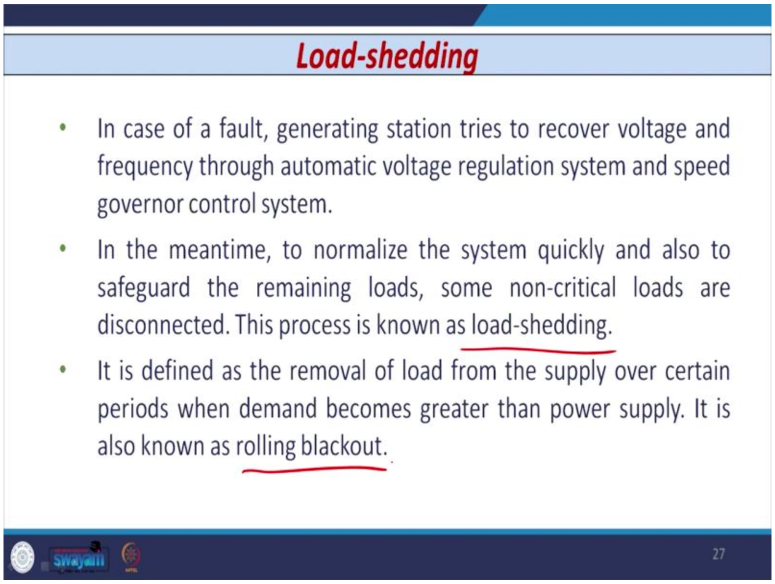

Now, the next point that is known as load-shedding, Now, whenever fault occurs, the generating station tries to recover voltage and frequency through some automatic voltage regulators as well as speed governing control system. In the meantime, to normalize the system quickly and also to safeguard the remaining loads, some non-critical loads need to be disconnected and this process is known as load-shedding process. Load-shedding process is defined as the removal of load from the supply over certain periods when the load demand that becomes greater than the supply demand. It is also known as the rolling blackout.

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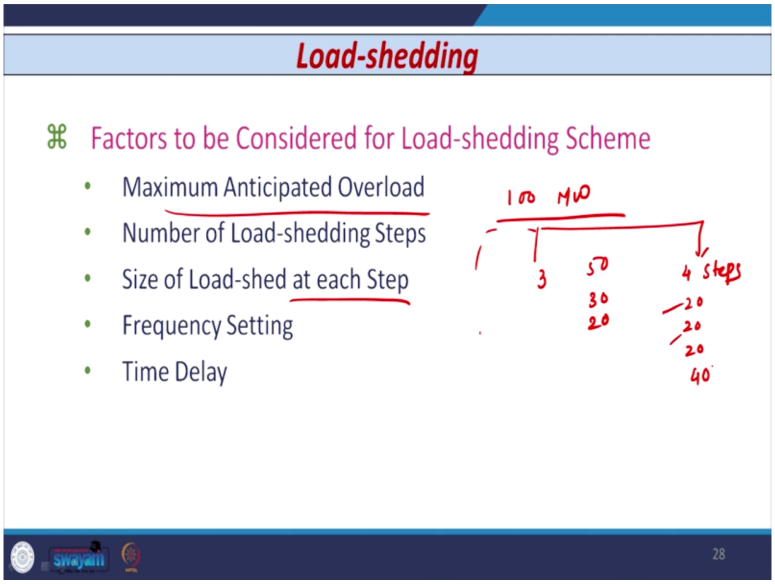

So, whenever you consider or whenever you go for load-shedding phenomenon, there are certain factors need to be considered for load-shedding scheme. These factors are maximum anticipated overload, so how much overload need to be anticipated. What is the number of load-shedding steps, suppose you need 100 megawatt load that is to be disconnected.

So what are the number of load-shedding steps, whether -- that means whether you are going to shed the load in three steps like this 50, 30, 20 or you are going to shed the load in, let us say, four steps, like say 20, 20, 20 and then 40 and so there are so many steps. So, number of load-shedding steps that also play an important role for load-shedding scheme.

Size of load-shed in each step, as I told you, whether how much load that needs to be shed for each step. Frequency setting of the frequency relays and the time delay that is adopted or given.

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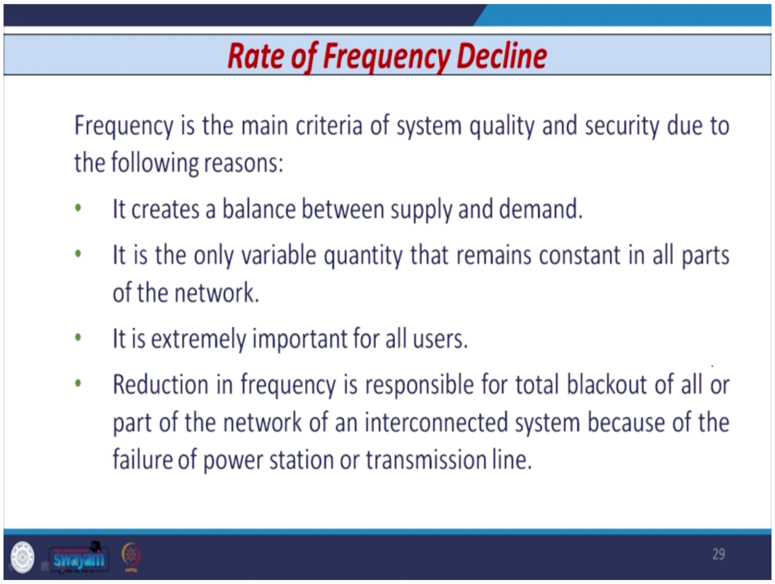

So, the rate of frequency decline. So, frequency setting or frequency is the main criteria of system quality and security due to many reasons; because it creates a balance between supply and demand; it is the only variable that remains constant throughout the whole power system network; and it is extremely user -- important for all users. So reduction in frequency that is responsible to total blackout of all or part of the network of an interconnected system because of the failure of power station or transmission line.

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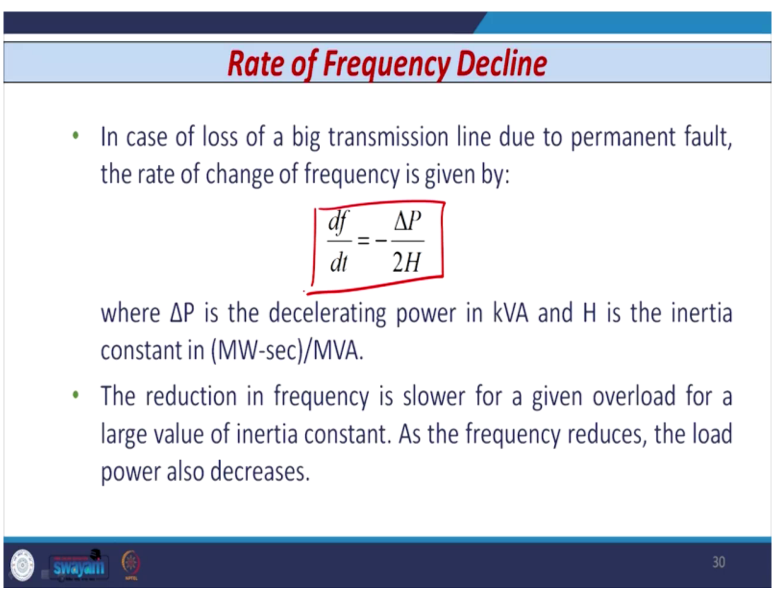

So, whenever there is a loss of big transmission line due to a fault, then the rate of change of frequency that is given by the equation df by dt that is equal to minus delta P by 2H, where delta P that is the decelerating power in kVA and H that is the inertia constant in megawatt second per MVA. The reduction in frequency is slower for a given overload for a larger value of inertia constant. So, if H is large, then the reduction in frequency that is also slower. As the frequency reduces, the load power also reduces.

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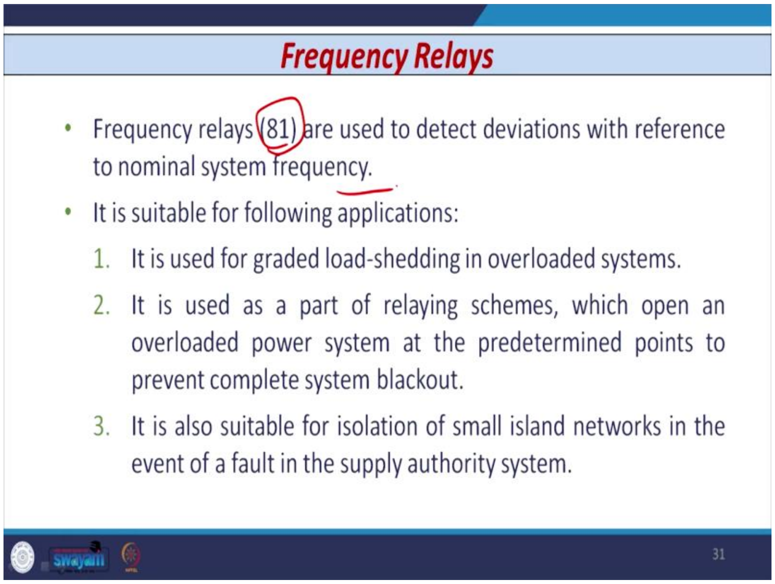

So, if I consider the frequency relays, the number given that is 81 that is used to detect a deviations frequency with reference to the nominal frequency in our case which is 50 hertz. So, it is suitable for following or various applications: it is used for the graded load-shedding in overloaded systems. It is used as a part of relaying schemes which open an overloaded power system at the predetermined points to prevent complete system blackout. And it is also suitable for isolation of small island networks in the event of fault in the supply authority system.

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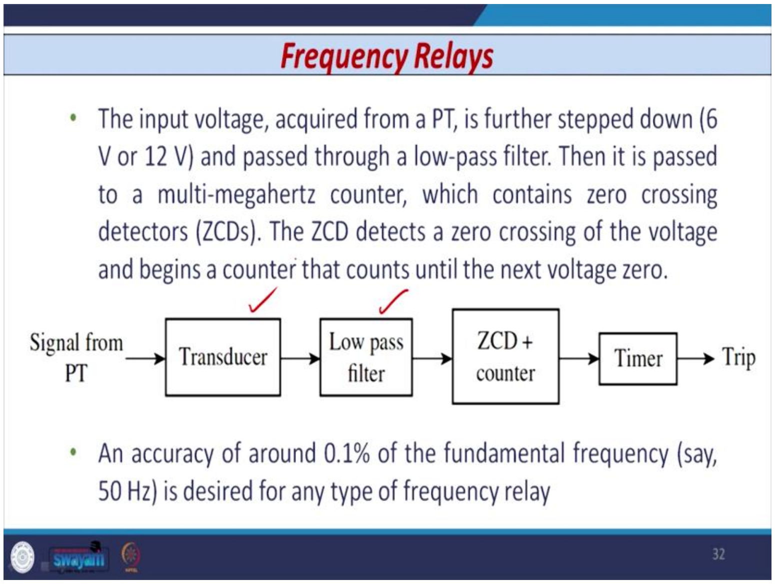

So, whenever we consider the frequency relays, this is the block diagram how the frequency that is going to be detected. So, you can see that the input voltage that is normally acquired through the PT, so secondary of PT, the voltage is available that is further step down maybe to a level of 6 to 12 volt and then passed through the low-pass filter.

So, here you have the transducer as well as the low-pass filter. Then it is passed to a multi-megahertz counter which contains the zero crossing detector, that is ZCD. So, ZCD detects a zero crossing of the voltage and begins or starts a counter that counts until the next voltage zero comes. So, an accuracy of around 0.1 percent of the fundamental frequency that is the 50 hertz that is desired for any type of frequency relay.

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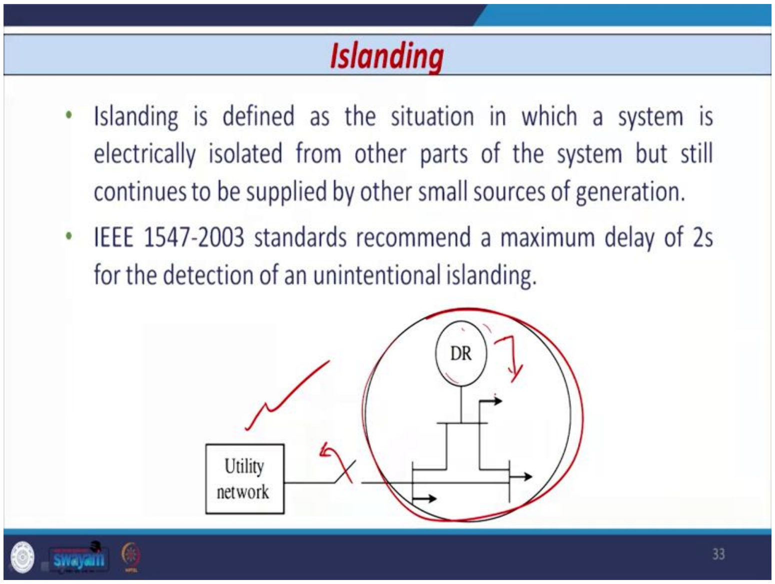

Now, with this background, let us discuss the phenomenon known as islanding. So, islanding is defined as the situation in which a system is electrically isolated from other parts of the system, but still those isolated system that continues to be supplied by some small sources of generation.

So, you can see here in this figure, this system that is shown by this that is isolated from the utility by opening up this breaker, but still this system that is supplied by this distributed resources. So whenever this type of phenomenon occurs, IEEE 1547 standards recommend a maximum delay of 2 second for the detection of an unintentional islanding. So, whenever islanding phenomenon occurs, then it needs to be detected within 2 second as per this standard.

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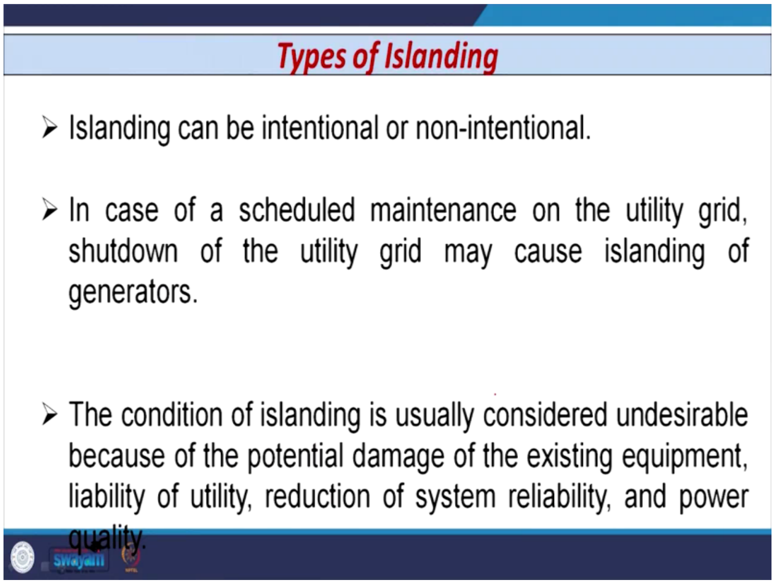

Now, there are basically two types of islanding, one is known as intentional islanding and another is known as non-intentional or unintentional islanding. In case of a scheduled maintenance on the utility grid, shutdown of utility grid may cause the islanding of generators and this is the case of intentional islanding. The condition of islanding is usually considered undesirable because of the potential damage to the existing equipment, liability of utility, reduction of system reliability and some power quality requirements.

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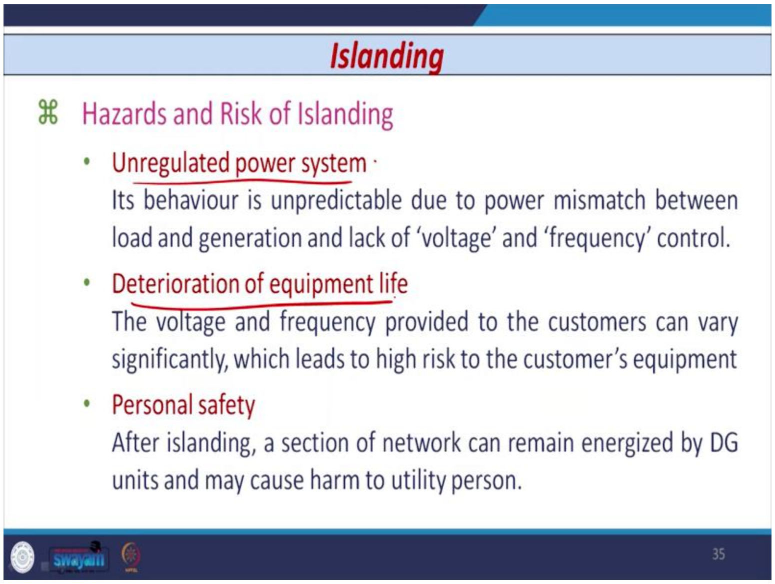

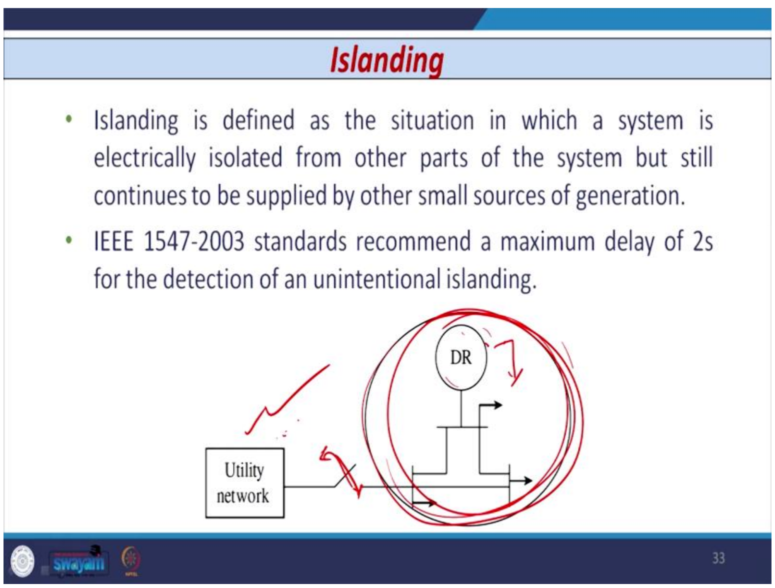

Now, let us discuss what are the hazards and risk of islanding. So, whenever island occurs or island is formed, then the first point that is the unregulated power system. You see that earlier case whenever, before the formation of island this breaker is closed. So, this system or all the equipment working in this area, it has a frequency that is same as the utility frequency and voltage that is also same as utility, because it is a regulated system.

However, whenever island is formed, the island in which the equipment are there, those are going to form the unregulated power system. So, the behavior is unpredictable due to the power mismatch between the load and generation and there is no control over frequency and voltage.

The second point is the deterioration of equipment life. The voltage and frequency provided to the customers can vary significantly which leads to the high risk of customers' equipment. And of course, after islanding, utility has to send linemen to repair or to carry out the maintenance. So a section that is known as island or network that remain energized by DG units and that may cause harm to the utility person.

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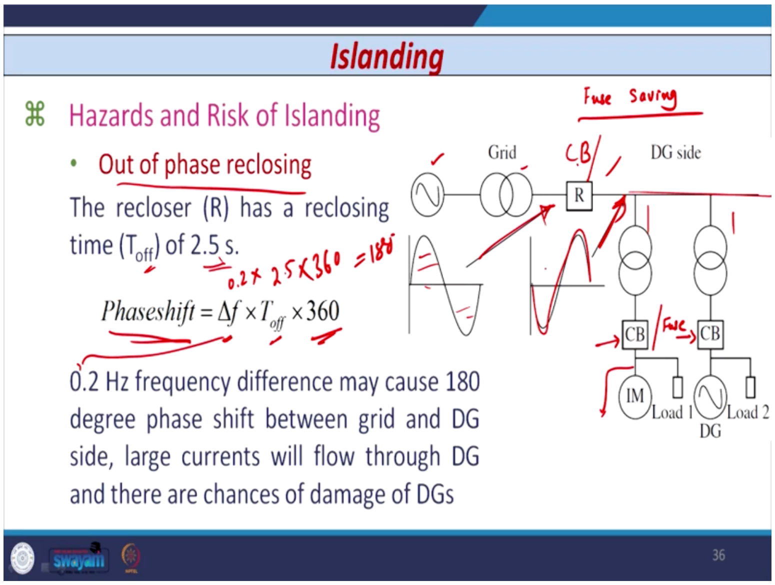

Now, one very important point which need to be considered that is the out of phase reclosing. So you can see that here I have shown the some source connected with the grid and then we have the circuit breaker which is equipped with reclosing facility and then you have the feeder and then you have the laterals. These are the laterals. So, as I told you in earlier class when we learned about the auto reclosing, in auto reclosing reclosers are widely used for the sake of fuse saving concept.

So, whenever the fault occurs on any of these laterals, then here you have the fuse or circuit breaker. So, whenever fault occurs on these laterals, fuse has to operate, but every time if faults are transient in nature then also fuse operates, so to avoid this, circuit breakers are equipped with reclosers. So, whenever fault occurs on these laterals, then these reclosers operate first and fuse is not going to operate. And if reclosers whenever reclose it and if faults are transient in nature, then they die out, so the system that again comes in normal condition. And hence, we can avoid the mal-operation of fuse and we can avoid the sending of lineman for every transient condition.

However, if I consider this situation, then you can see that this recloser has a reclosing time of let us say 2.5 seconds. So, if I consider this point, the voltage wave shape is like this and if I consider this point beyond the recloser, then the phaseshift that is given by delta f that is the change in frequency, then the off nominal time of the recloser and into 360.

So, if you calculate, put this value 2.5 and delta f maybe some value, then let us say delta f that is only very small 0.2 hertz frequency difference, then phaseshift comes out to be 180 degree. If you put it here 0.2 into 2.5 into 360, then this comes out to be 180 degree. So, if you just check the waveform here, then the wave shape that is exactly 180 degree out of phase.

If this situation is there and if you reclose the circuit breaker because of the to avail the advantage of fuse saving concept in distribution system, then in this situation whatever loads you are connected those loads are going to damage because high magnitude of current that flows because of 180 degree phaseshift exists between the grid and the DG side supply voltage. So, loads, definitely, those loads are going to damage.

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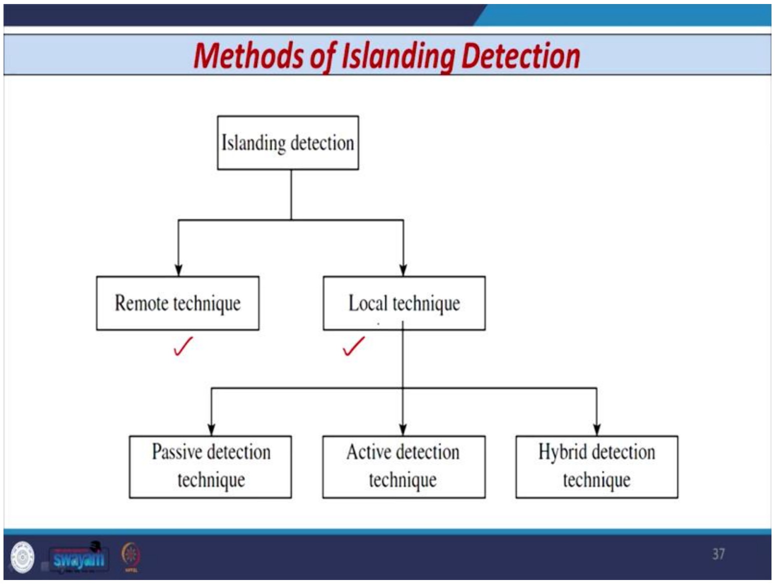

So, to avoid this, islanding needs to be detected. So, there are different methods of islanding detection. The techniques are known as remote technique and local technique. And again the local technique, that is again classified as passive technique, active technique and hybrid technique.

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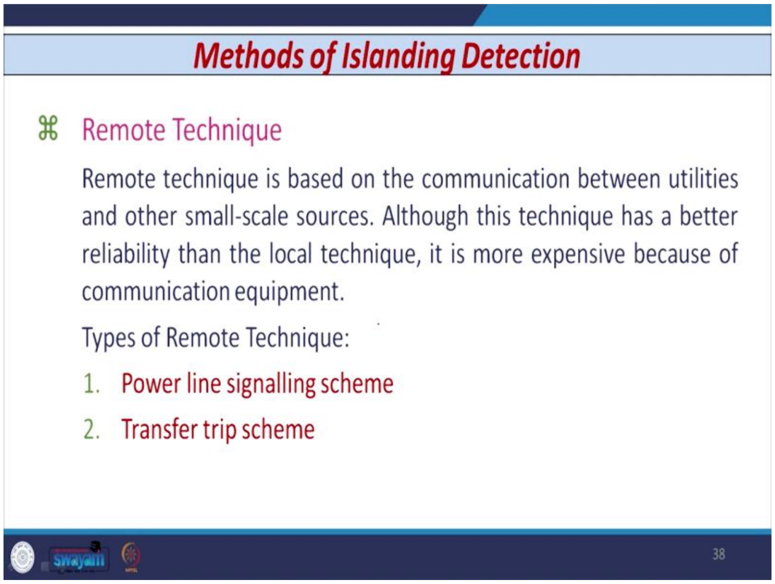

So, if I consider the remote technique, then the remote technique is used on the -- it is based on the communication between utilities and the distributed energy resources. This technique is basically classified as the power line signaling scheme and transfer trip scheme.

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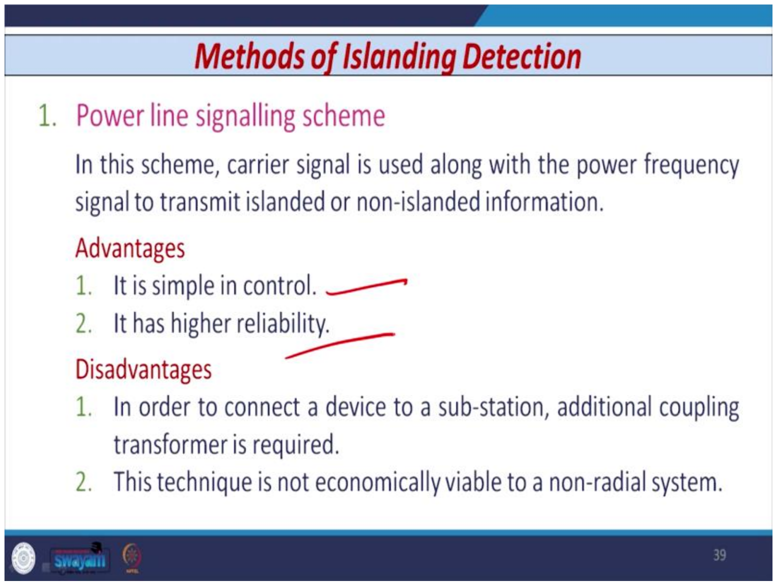

So, if I consider power line signaling scheme, then the carrier signal is used along with the fundamental 50 hertz signal to transmit the islanded or non-islanded information. This scheme is simple and has higher reliability. However, in order to connect the device in sub-station, additional coupling transformer is required and this technique is not economically viable for a non-radial system.

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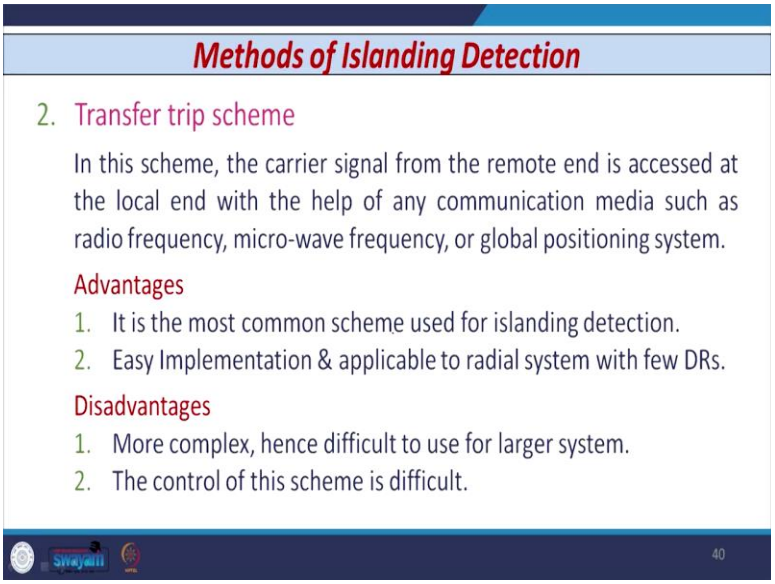

The next remote scheme is transfer trip scheme. So, here in this scheme, the carrier signal from the remote end is assessed at the local end with the help of communication mediums such as radio frequency, micro-wave frequency or GPS. The advantage of transfer trip scheme is it is the most common scheme used for islanding detection and it can be easily implementable. However, it's -- the whole scheme is very complex and difficult to use for larger system and control of this scheme is difficult.

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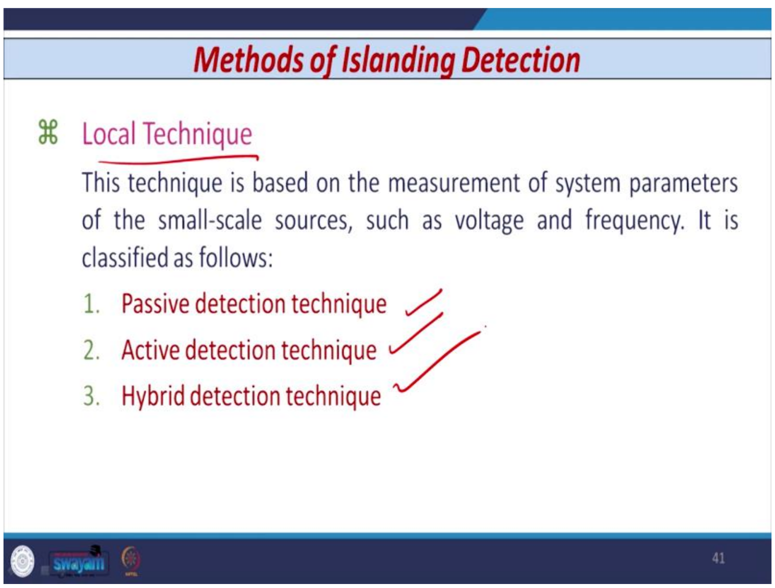

So, if I consider the local technique which does not require any communication medium, then this technique is based on measurement of certain system parameters like voltage, frequency, impedance or rate of change of voltage, rate of change of frequency like that. And this scheme is classified as passive scheme, active scheme, and hybrid scheme.

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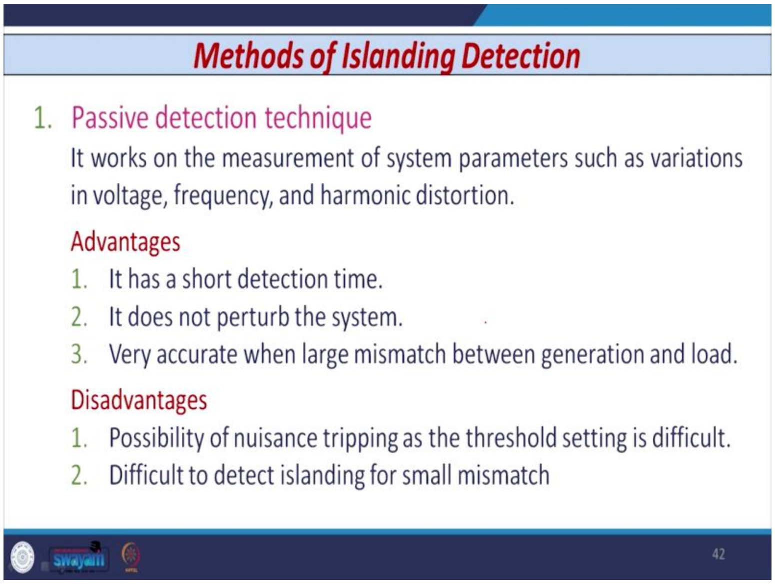

So, if I consider passive islanding detection technique, then it works on the measurement of system parameters such as variation in voltage, frequency and harmonic distortion. So, the main advantage of passive scheme that is it has a short detection time, it does not perturb the system, and it is very accurate when there is a large mismatch exists between the generation and load.

However, possibility of nuisance tripping for passive detection scheme that may exist because it depends on threshold setting and it is difficult to detect islanding when the mismatch between the generation and load that is very small, say 10 percent or lower.

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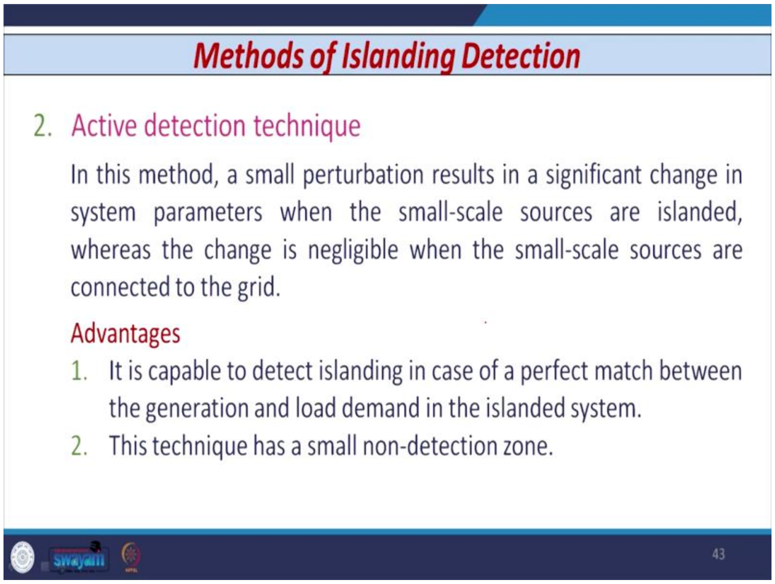

So, the scheme used in that case that is active detection technique. So, in this scheme, a small perturbation results in a significant change in the system parameters when the small scale sources are islanded, whereas the change is negligible when small scale sources are connected to the grid.

So, the main advantage of this scheme is it is capable to detect islanding in case of perfect power balance situation and this technique has small non-detection zone. Non-detection zone is the region in which if any islanding phenomenon occurs then the -- your scheme is not capable to detect that phenomenon. So that is known as non-detection zone.

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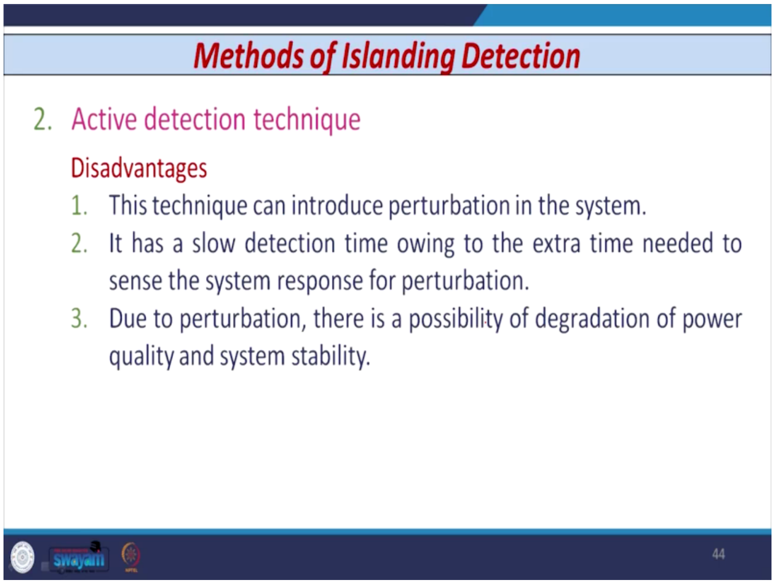

However, there are certain disadvantages of active detection scheme. The main disadvantage is that this technique can introduce perturbation in the system. So, it has low detection time owing to the extra time required to sense the system response for perturbation. And due to perturbation, there is a possible of degradation of power quality and system stability.

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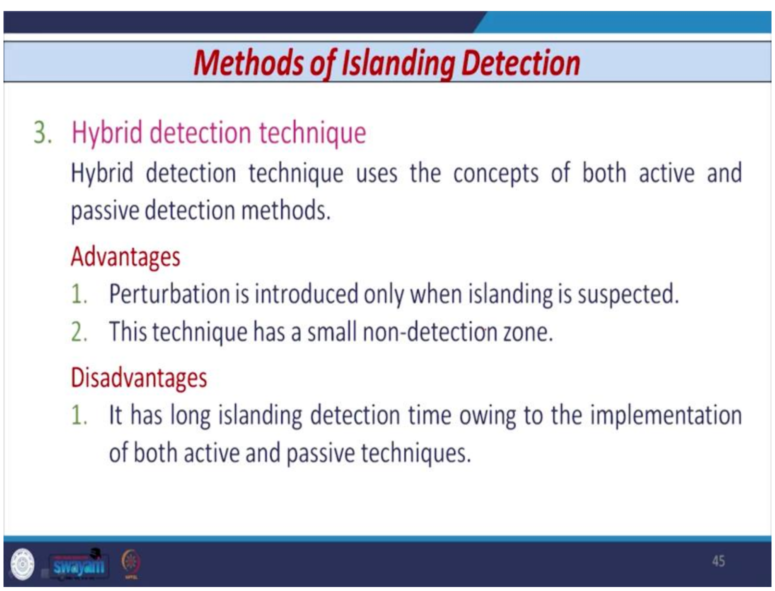

And the last scheme that is known as hybrid detection technique that uses both active and passive scheme. The main advantage of this scheme is that this scheme has a very small non-detection zone and the perturbation is introduced only when the islanding is suspected. However, it has a long islanding detection time because of the implementation of both active and passive technique.

So, in this lecture, we started our discussion with the different types of lightning arrester, and then, we started our discussion with the whenever any blackout occurs, then what will be the strategy in case of blackout, what is the islanding phenomena and what are the various techniques using which we can detect the islanding condition. I stop here. Thank you.