

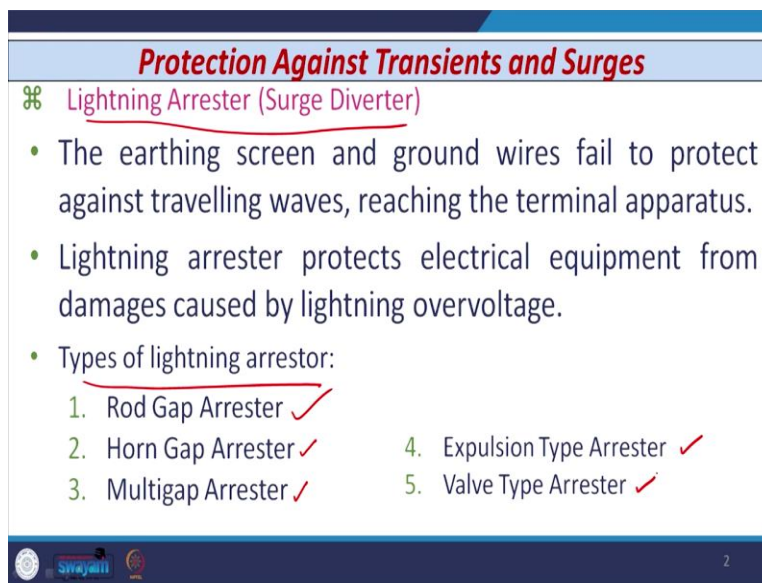
Power System Protection and Switchgear
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Lecture 33

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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Protection Against Transients and Surges

⌘ Lightning Arrester (Surge Diverter)

- The earthing screen and ground wires fail to protect against travelling waves, reaching the terminal apparatus.
- Lightning arrester protects electrical equipment from damages caused by lightning overvoltage.
- Types of lightning arrester:
 1. Rod Gap Arrester ✓
 2. Horn Gap Arrester ✓
 3. Multigap Arrester ✓
 4. Expulsion Type Arrester ✓
 5. Valve Type Arrester ✓

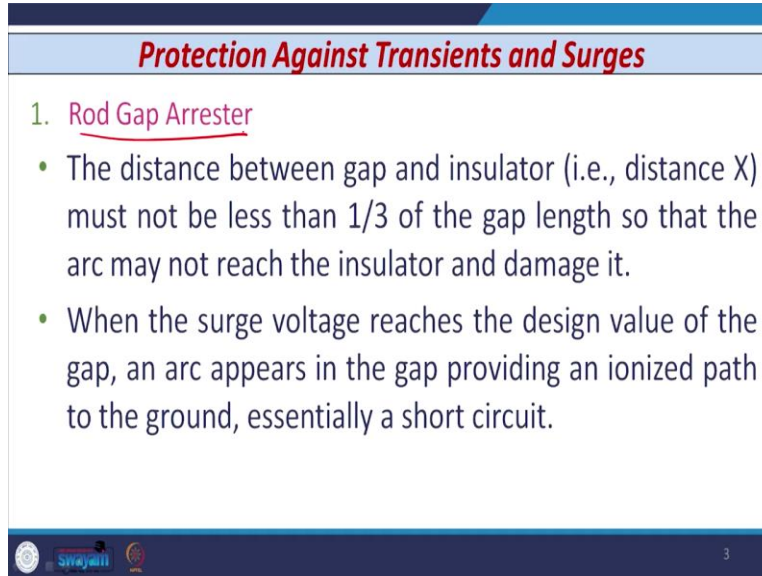
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So, as we have discussed that there are several equipment use for protection against surges and transients, we started with the shielding or the earthing screen, then second we have discussed the main thing that is ground wire, the third we have discussed 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 arrester; 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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Protection Against Transients and Surges

1. Rod Gap Arrester
 - The distance between gap and insulator (i.e., distance X) must not be less than $\frac{1}{3}$ of the gap length so that the arc may not reach the insulator and damage it.
 - When the surge voltage reaches the design value of the gap, an arc appears in the gap providing an ionized path to the ground, essentially a short circuit.

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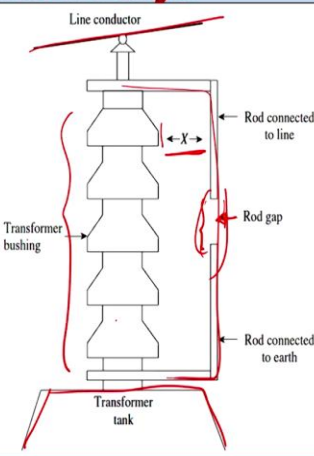
So the first type of arrester that is known as the rod gap arrester. So, in rod gap arrester, the distance between the gap and the insulator, let us say some X distance that must not be less than one-third of the gap length, otherwise, there are fair chances of the arcing. So, if we maintain this distance, 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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Protection Against Transients and Surges

1. Rod Gap Arrester

- Therefore, a rod gap should be so set that it breaks down to a voltage not less than 30% below the voltage withstand level of the equipment to be protected.



The diagram illustrates a rod gap arrester. At the top, a line conductor is connected to a rod labeled 'Rod connected to line'. Below this rod is a transformer bushing, which is part of a transformer tank. The distance between the rod and the bushing is labeled 'X'. Below the bushing is another rod labeled 'Rod connected to earth'. The gap between these two rods is labeled 'Rod gap'. The transformer tank is shown at the bottom.

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Protection Against Transients and Surges

1. Rod Gap Arrester

- The distance between gap and insulator (i.e., distance X) must not be less than $\frac{1}{3}$ of the gap length so that the arc may not reach the insulator and damage it.
- When the surge voltage reaches the design value of the gap, an arc appears in the gap providing an ionized path to the ground, essentially a short circuit.

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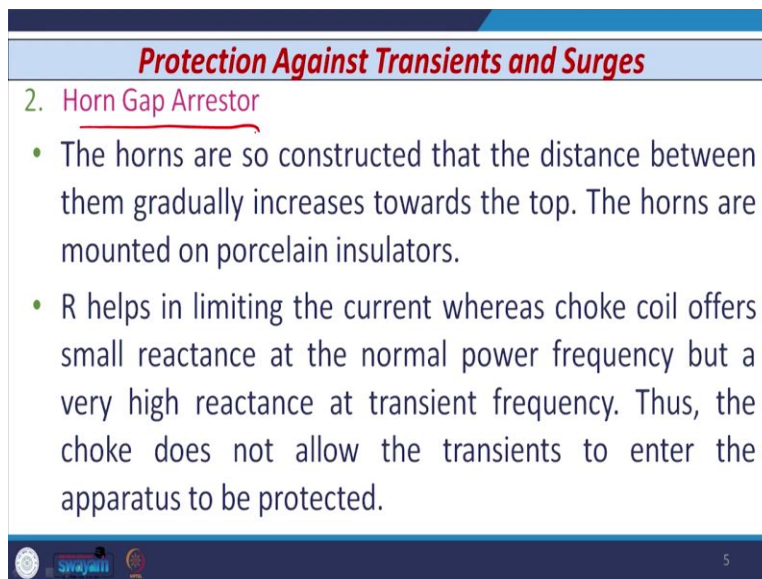
So, you can see here, I have shown the figure of the rod gap arrester. So, these are the transformer bushings and this is the transformer tank and on upper side you have the line conductor with insulators are there. So with this insulator, there is a one rod connected to the line it is known as line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

2. Horn Gap Arrestor

- The horns are so constructed that the distance between them gradually increases towards the top. The horns are mounted on porcelain insulators.
- R helps in limiting the current whereas choke coil offers small reactance at the normal power frequency but a very high reactance at transient frequency. Thus, the choke does not allow the transients to enter the apparatus to be protected.

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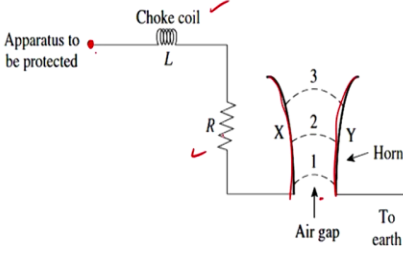
The second type of the arrester that is known as the horn gap arrester. So the name itself suggests contains the horns and these horns are so constructed that the distance between the horns that is gradually increases towards the top. So as you move from the bottom to the top, the distance between these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

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Protection Against Transients and Surges

2. **Horn Gap Arrestor**

On the occurrence of an overvoltage, arc moves upward into positions 1, 2, and 3. At 3, the distance may be too large, which results in a high resistance to the arc, and, the arc is extinguished.



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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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Protection Against Transients and Surges

2. Horn Gap Arrestor

- The horns are so constructed that the distance between them gradually increases towards the top. The horns are mounted on porcelain insulators.
- R helps in limiting the current whereas choke coil offers small reactance at the normal power frequency but a very high reactance at transient frequency. Thus, the choke does not allow the transients to enter the apparatus to be protected.

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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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Protection Against Transients and Surges

2. Horn Gap Arrestor

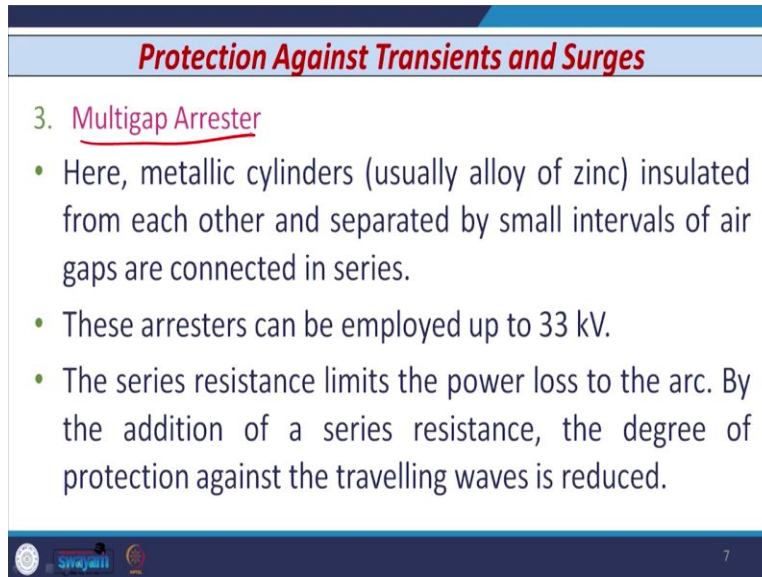
On the occurrence of an overvoltage, arc moves upward into positions 1, 2, and 3. At 3, the distance may be too large, which results in a high resistance to the arc, and, the arc is extinguished.

$V_R = \frac{3L \dot{I}}{A}$

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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Protection Against Transients and Surges

3. Multigap Arrester

- Here, metallic cylinders (usually alloy of zinc) insulated from each other and separated by small intervals of air gaps are connected in series.
- These arresters can be employed up to 33 kV.
- The series resistance limits the power loss to the arc. By the addition of a series resistance, the degree of protection against the travelling waves is reduced.

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The third type of arrester that is known as the multigap arrester. 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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Protection Against Transients and Surges

3. Multigap Arrester

- During an O/V., the breakdown of the series gap X to Y occurs first. Hence, high magnitude current is diverted into earth through the path of the shunted gaps by cylinders Y and Z, instead of from the shunt resistance.

The diagram shows a horizontal line representing a power line. On the left, it is labeled 'Line'. Along the line, there are three gaps: 'X', 'Y', and 'Z'. Below 'X' is the label 'Series gaps' with a red underline. Below 'Y' and 'Z' is the label 'Shunted gaps' with a red underline. A shunt resistor is connected between the line and ground between points Y and Z, labeled 'Shunt resistance'. To the right of point Z, there is a series resistor labeled 'Series resistance' with a red underline. The entire diagram is enclosed in a blue border with a white background.

So, as I told you, multiple gaps are provided. So, you can see that in this figure, I have shown the multigap arrester, 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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Protection Against Transients and Surges

4. Expulsion Type Arrester

- This type of arrester is also called protector tube and is commonly used on systems operating at voltages upto 33 kV.
- It essentially consists of a rod gap X-Y in series with a second gap enclosed within the fibre tube. The gap in the fibre tube is formed by two electrodes. The upper electrode is connected to the rod gap and the lower electrode to the earth.

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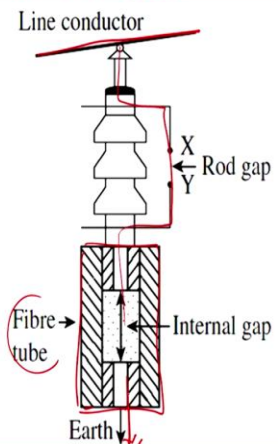
The fourth type of lightning arrester that is known as the expulsion type lightning arrester. So, this type of arrester is also called the protector tube and it is commonly used for the system operating at voltage up to 33 kV. So it essentially consists of a rod gap X-Y in series with a second gap enclosed 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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Protection Against Transients and Surges

4. Expulsion Type Arrester

- The arc is confined to the space inside the relatively small fibre tube.
- Due to vaporization, high pressure gases are formed which expelled through the vent at the lower end of the tube.



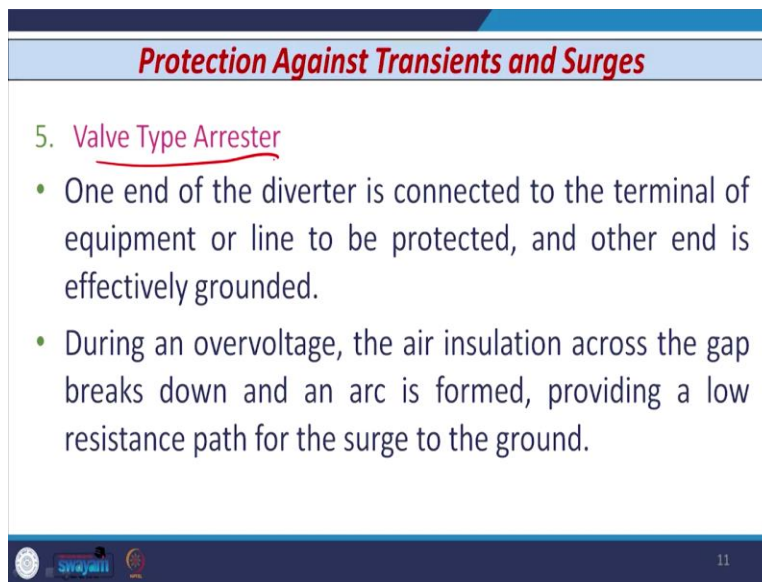
The diagram illustrates the internal structure of an expulsion type arrester. At the top, a 'Line conductor' is connected to a 'Rod gap' between points X and Y. Below the rod gap is a 'Fibre tube' which contains an 'Internal gap' between two electrodes. The bottom of the fibre tube is connected to 'Earth'. A red circle highlights the internal gap area.

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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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Protection Against Transients and Surges

5. Valve Type Arrester

- One end of the diverter is connected to the terminal of equipment or line to be protected, and other end is effectively grounded.
- 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.

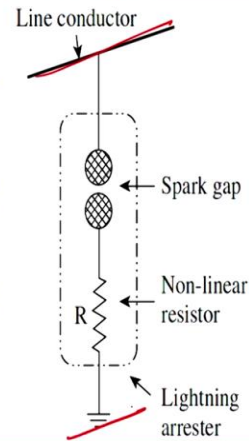
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Protection Against Transients and Surges

5. Valve Type Arrester

There are two types of valve arresters:

1. Silicon Carbide (SiC) Lightning Arrester
2. Metal Oxide Lightning Arrester



The next type of arrester that is known as valve type arrester. 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 arrester 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.

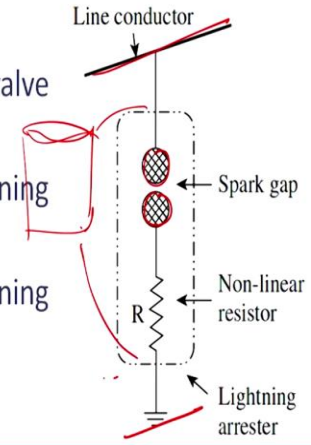
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Protection Against Transients and Surges

5. Valve Type Arrester

There are two types of valve arresters:

1. Silicon Carbide (SiC) Lightning Arrester
2. Metal Oxide Lightning Arrester



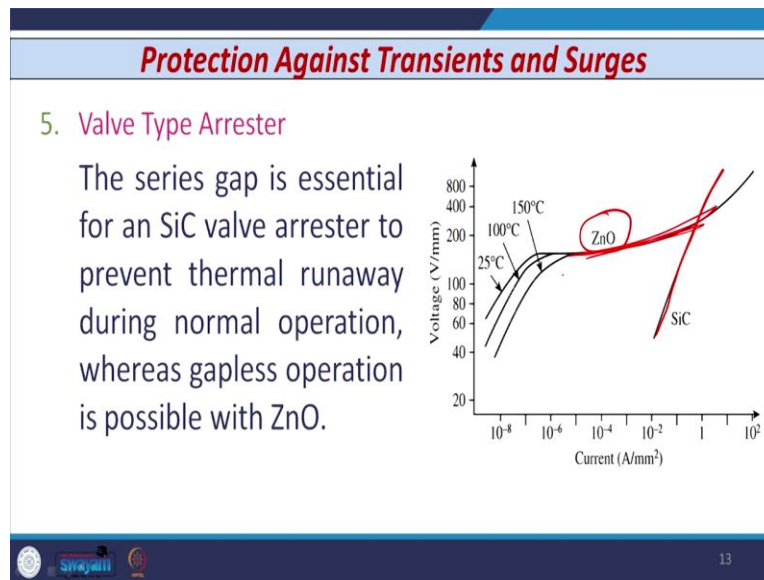
The diagram illustrates the internal components of a valve type arrester. A line conductor is connected to a spark gap, which is in series with a non-linear resistor (labeled 'R'). This series combination is connected to a lightning arrester, which is grounded. A red cylinder-shaped component is shown to the left of the spark gap and resistor, representing the physical housing of the arrester.

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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 arrester, 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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Common Ratings of Lightning/Surge Arresters

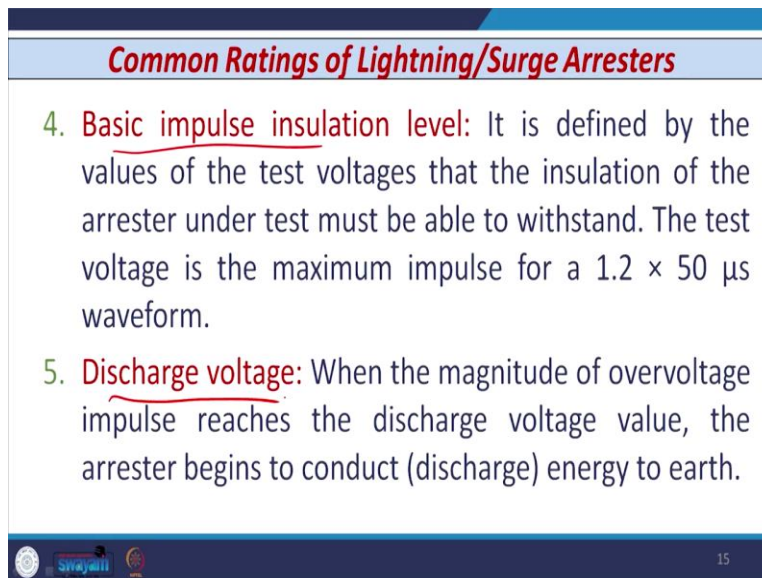
1. **Rated voltage:** It is the maximum continuous operating voltage, which is the steady-state voltage the arrester could support for an indefinite time.
2. **Rated current:** Arresters are tested with 8/20 μ s discharge current waves of varying peak magnitudes (1.5 kA to 20 kA) with the resulting peak discharge voltages.
3. **Normal voltage:** It is the nominal continuous voltage that the arrester can withstand before flashover.

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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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Common Ratings of Lightning/Surge Arresters

4. **Basic impulse insulation level:** It is defined by the values of the test voltages that the insulation of the arrester under test must be able to withstand. The test voltage is the maximum impulse for a $1.2 \times 50 \mu\text{s}$ waveform.
5. **Discharge voltage:** When the magnitude of overvoltage impulse reaches the discharge voltage value, the arrester begins to conduct (discharge) energy to earth.

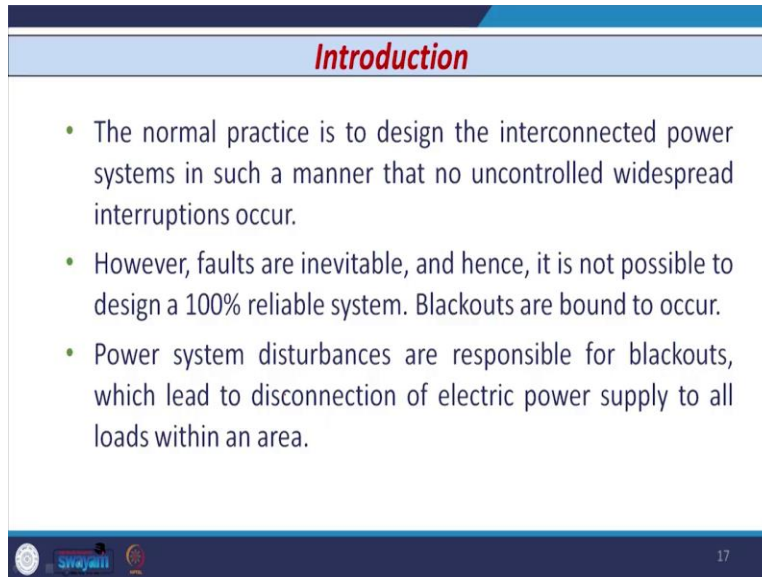
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The fifth that is the basic impulse insulation level. So, basic impulse insulation level is defined by the values of the test voltage that the insulation of the arrester under test must be able to withstand. So whenever you test the arrester, the insulation 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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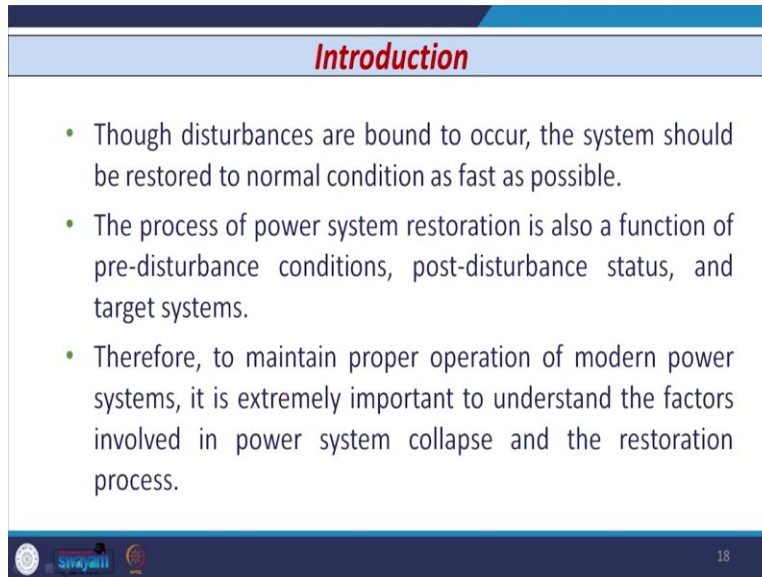
Introduction

- The normal practice is to design the interconnected power systems in such a manner that no uncontrolled widespread interruptions occur.
- However, faults are inevitable, and hence, it is not possible to design a 100% reliable system. Blackouts are bound to occur.
- Power system disturbances are responsible for blackouts, which lead to disconnection of electric power supply to all loads within an area.

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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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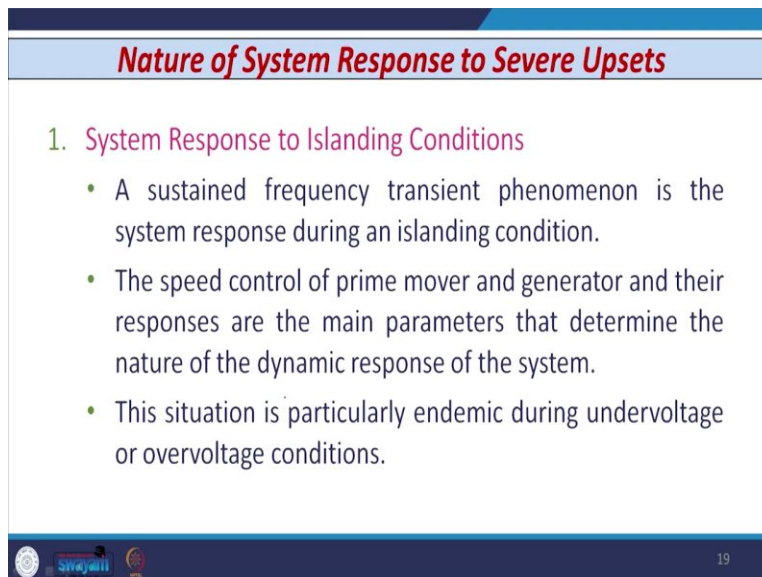
Introduction

- Though disturbances are bound to occur, the system should be restored to normal condition as fast as possible.
- The process of power system restoration is also a function of pre-disturbance conditions, post-disturbance status, and 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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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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Nature of System Response to Severe Upsets

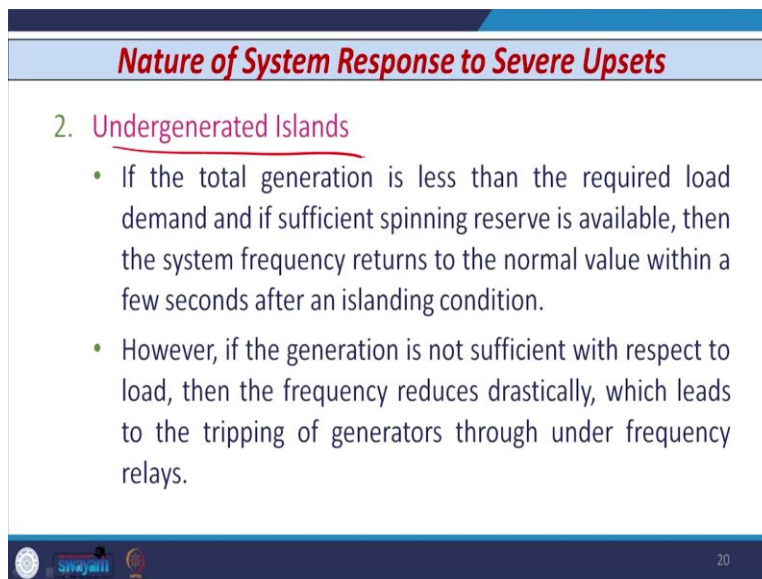
1. **System Response to Islanding Conditions**
 - A sustained frequency transient phenomenon is the system response during an islanding condition.
 - The speed control of prime mover and generator and their responses are the main parameters that determine the nature of the dynamic response of the system.
 - This situation is particularly endemic during undervoltage or overvoltage conditions.

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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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Nature of System Response to Severe Upsets

2. Undergenerated Islands

- If the total generation is less than the required load demand and if sufficient spinning reserve is available, then the system frequency returns to the normal value within a few seconds after an islanding condition.
- However, if the generation is not sufficient with respect to load, then the frequency reduces drastically, which leads to the tripping of generators through under frequency relays.

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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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Nature of System Response to Severe Upsets

2. Undergenerated Islands

- Underfrequency load-shedding schemes are usually used, which reduces the connected load that can be satisfactorily supplied by the available generators.
- Consequently, in an undergenerated islanding condition, the initial transient depends on the load-shedding scheme, whereas the response of the system frequency depends on the characteristics of the prime mover.

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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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Nature of System Response to Severe Upsets

3. Over-generated Islands

- In an over-generated islanding condition, the system frequency increases and the mechanical power generated by the turbines reduces.
- Therefore, the ability of power plants to sustain a partial load rejection will decide the performance of the system.

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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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Nature of System Response to Severe Upsets

4. Grid Integration of Renewable Energy Sources ✓

- Interconnection of various types of DGs at different voltage levels is important.
- IEEE 1547, 2003 has given guidelines for interconnection and requirements of DGs in to the grid.

Transmission grid	> 132 kV	Large power plants
High voltage distribution grid	66-132 kV	Large industrial CHP Large-scale hydro offshore wind parks
Medium voltage distribution grid	11-66 kV	
Low voltage distribution grid	230-415 V	Individual photovoltaic panels Microchip-CHP systems

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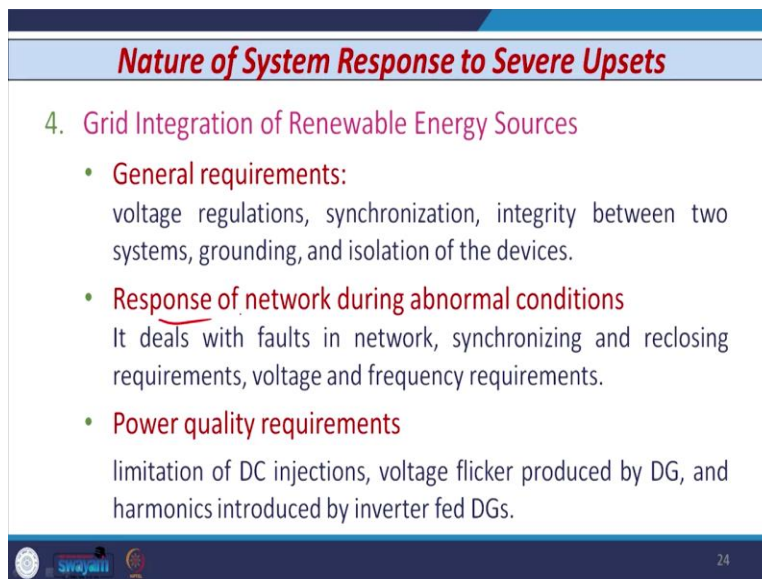
Now, if I consider the present scenario, then we know that the integration of renewable energy sources that is increasing day by day and this penetration of renewable energy sources maybe photovoltaic or wind or some other that is entering the grid, conventional grid, maybe at distribution level or medium 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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Nature of System Response to Severe Upsets

4. Grid Integration of Renewable Energy Sources

- **General requirements:**
voltage regulations, synchronization, integrity between two systems, grounding, and isolation of the devices.
- **Response of network during abnormal conditions**
It deals with faults in network, synchronizing and reclosing requirements, voltage and frequency requirements.
- **Power quality requirements**
limitation of DC injections, voltage flicker produced by DG, and harmonics introduced by inverter fed DGs.

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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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Nature of System Response to Severe Upsets

- 5. Reactive Power Balance**
 - Reactive power balance affects the system performance. A significant difference between the reactive power generated and absorbed may lead to overvoltage or undervoltage conditions.
- 6. Power Plant Auxiliaries**
 - The performance of power plant auxiliaries can deteriorate because of the reduction in supply voltage and frequency.

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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.

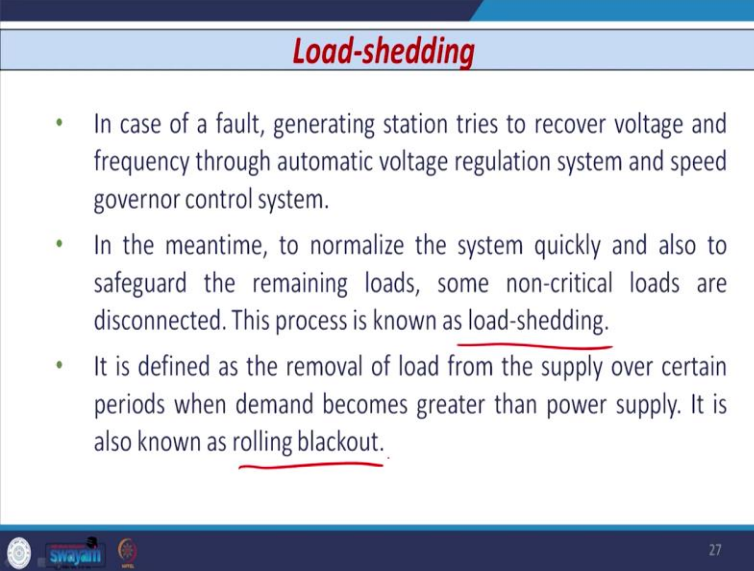
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The slide features a blue header with the title "Nature of System Response to Severe Upsets" in red. Below the header, the section "7. Power System Restoration" is underlined in red. It contains two bullet points: the first describes the steps of restoration (generating units, loads, balance, and resynchronization), and the second lists methods to speed up the process (captive power plants, diesel, and gas-based generator sets). The footer includes a logo, the text "Swayam", and the number "26".

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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Load-shedding

- In case of a fault, generating station tries to recover voltage and frequency through automatic voltage regulation system and speed governor control system.
- In the meantime, to normalize the system quickly and also to safeguard the remaining loads, some non-critical loads are disconnected. This process is known as load-shedding.
- It is defined as the removal of load from the supply over certain periods when demand becomes greater than power supply. It is also known as rolling blackout.

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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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Load-shedding

⌘ Factors to be Considered for Load-shedding Scheme

- Maximum Anticipated Overload
- Number of Load-shedding Steps
- Size of Load-shed at each Step
- Frequency Setting
- Time Delay

The diagram illustrates a load-shedding scheme for a 100 MW load. It shows a tree structure starting from 100 MW at the top. A vertical line descends from 100 MW, with a horizontal line branching to the left labeled '3'. The vertical line continues down to 50 MW. From 50 MW, a horizontal line branches to the left labeled '30', and the vertical line continues down to 20 MW. From 20 MW, a horizontal line branches to the left labeled '20', and the vertical line continues down to another 20 MW. From this final 20 MW, a horizontal line branches to the left labeled '20', and the vertical line continues down to 40 MW. To the right of the diagram, the text '4 steps' is written with arrows pointing to the four horizontal branching lines.

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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Rate of Frequency Decline

Frequency is the main criteria of system quality and security due to the following reasons:

- It creates a balance between supply and demand.
- It is the only variable quantity that remains constant in all parts of the network.
- It is extremely important for all users.
- Reduction in frequency is responsible for 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, 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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Rate of Frequency Decline

- In case of loss of a big transmission line due to permanent fault, the rate of change of frequency is given by:

$$\frac{df}{dt} = -\frac{\Delta P}{2H}$$

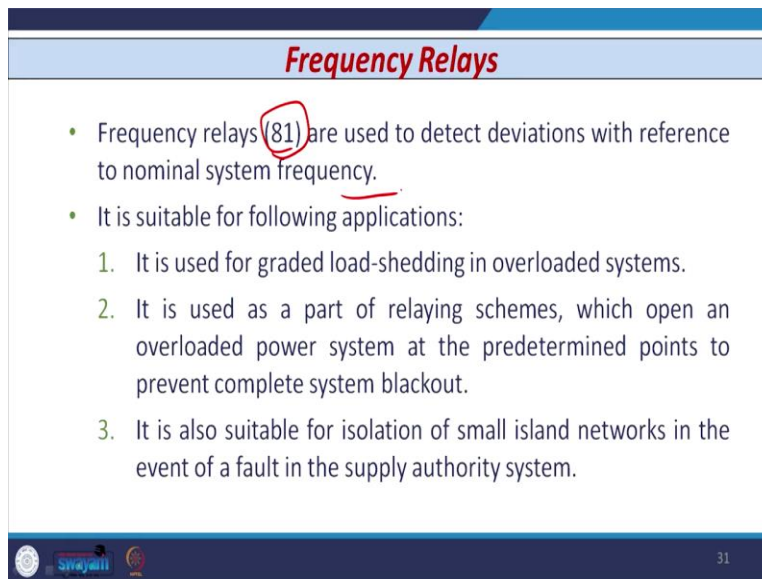
where ΔP is the decelerating power in kVA and H is the inertia constant in (MW-sec)/MVA.

- The reduction in frequency is slower for a given overload for a large value of inertia constant. As the frequency reduces, the load power also decreases.

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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 $\frac{df}{dt}$ that is equal to $-\frac{\Delta P}{2H}$, where ΔP 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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Frequency Relays

- Frequency relays (81) are used to detect deviations with reference to nominal system frequency.
- It is suitable for following applications:
 1. It is used for graded load-shedding in overloaded systems.
 2. It is used as a part of relaying schemes, which open an overloaded power system at the predetermined points to prevent complete system blackout.
 3. It is also suitable for isolation of small island networks in the event of a fault in the supply authority system.

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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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Frequency Relays

- The input voltage, acquired from a PT, is further stepped down (6 V or 12 V) and passed through a low-pass filter. Then it is passed to a multi-megahertz counter, which contains zero crossing detectors (ZCDs). The ZCD detects a zero crossing of the voltage and begins a counter that counts until the next voltage zero.

```
graph LR; A[Signal from PT] --> B[Transducer]; B --> C[Low pass filter]; C --> D[ZCD + counter]; D --> E[Timer]; E --> F[Trip]
```

- An accuracy of around 0.1% of the fundamental frequency (say, 50 Hz) is desired for any type of frequency relay

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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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Islanding

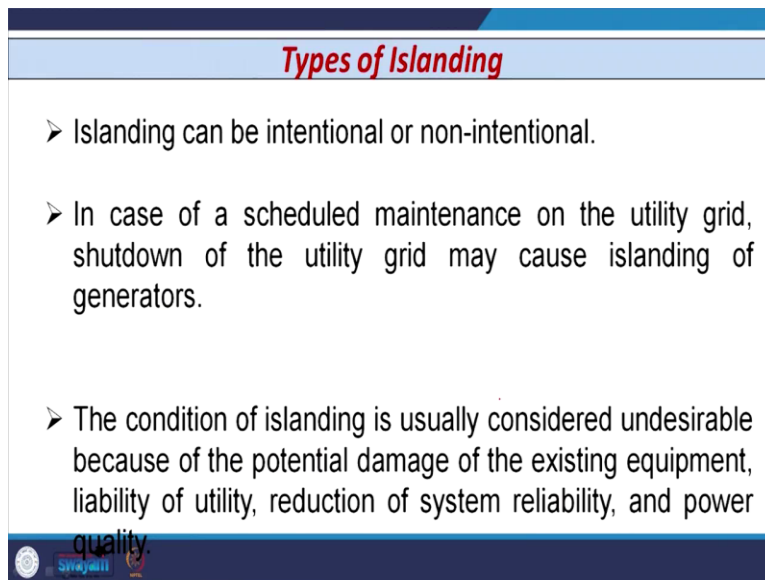
- Islanding is defined as the situation in which a system is electrically isolated from other parts of the system but still continues to be supplied by other small sources of generation.
- IEEE 1547-2003 standards recommend a maximum delay of 2s for the detection of an unintentional islanding.

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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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Types of Islanding

- Islanding can be intentional or non-intentional.
- In case of a scheduled maintenance on the utility grid, shutdown of the utility grid may cause islanding of generators.
- The condition of islanding is usually considered undesirable because of the potential damage of the existing equipment, liability of utility, reduction of system reliability, and power quality.

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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Islanding

⌘ **Hazards and Risk of Islanding**

- **Unregulated power system**
Its behaviour is unpredictable due to power mismatch between load and generation and lack of 'voltage' and 'frequency' control.
- **Deterioration of equipment life**
The voltage and frequency provided to the customers can vary significantly, which leads to high risk to the customer's equipment
- **Personal safety**
After islanding, a section of network can remain energized by DG units and may cause harm to utility person.

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Islanding

- Islanding is defined as the situation in which a system is electrically isolated from other parts of the system but still continues to be supplied by other small sources of generation.
- IEEE 1547-2003 standards recommend a maximum delay of 2s for the detection of an unintentional islanding.

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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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Islanding

⌘ Hazards and Risk of Islanding

- Out of phase reclosing

The recloser (R) has a reclosing time (T_{off}) of 2.5 s.

$0.2 \times 2.5 \times 360 = 180^\circ$

$Phaseshift = \Delta f \times T_{off} \times 360$

0.2 Hz frequency difference may cause 180 degree phase shift between grid and DG side, large currents will flow through DG and there are chances of damage of DGs

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

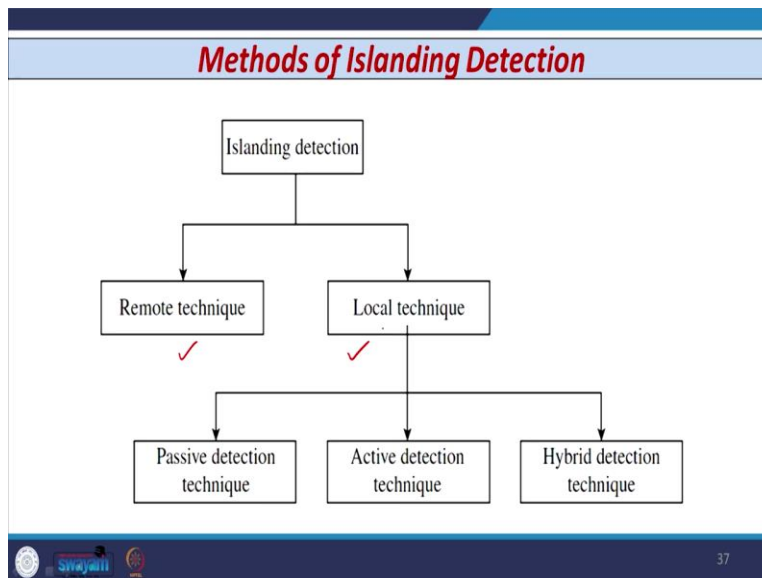
time if faults are transient in nature then also fuse operates, so to avoid this, circuit breakers are equipped with reclosers. So, whenever fault occurs on these laterals, then these reclosers operate first and fuse is not going to operate. And if reclosers whenever reclose it and if faults are transient 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 Δf 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 Δf maybe some value, then let us say Δf 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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Remote Technique

Remote technique is based on the communication between utilities and other small-scale sources. Although this technique has a better reliability than the local technique, it is more expensive because of communication equipment.

Types of Remote Technique:

1. Power line signalling scheme
2. Transfer trip scheme

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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Methods of Islanding Detection

- 1. Power line signalling scheme**
In this scheme, carrier signal is used along with the power frequency signal to transmit islanded or non-islanded information.
Advantages
 1. It is simple in control.
 2. It has higher reliability.**Disadvantages**
 1. In order to connect a device to a sub-station, additional coupling transformer is required.
 2. This technique is not economically viable to a non-radial system.

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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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Methods of Islanding Detection

2. **Transfer trip scheme**

In this scheme, the carrier signal from the remote end is accessed at the local end with the help of any communication media such as radio frequency, micro-wave frequency, or global positioning system.

Advantages

1. It is the most common scheme used for islanding detection.
2. Easy Implementation & applicable to radial system with few DRs.

Disadvantages

1. More complex, hence difficult to use for larger system.
2. The control of this scheme is difficult.

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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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Methods of Islanding Detection

⌘ **Local Technique**

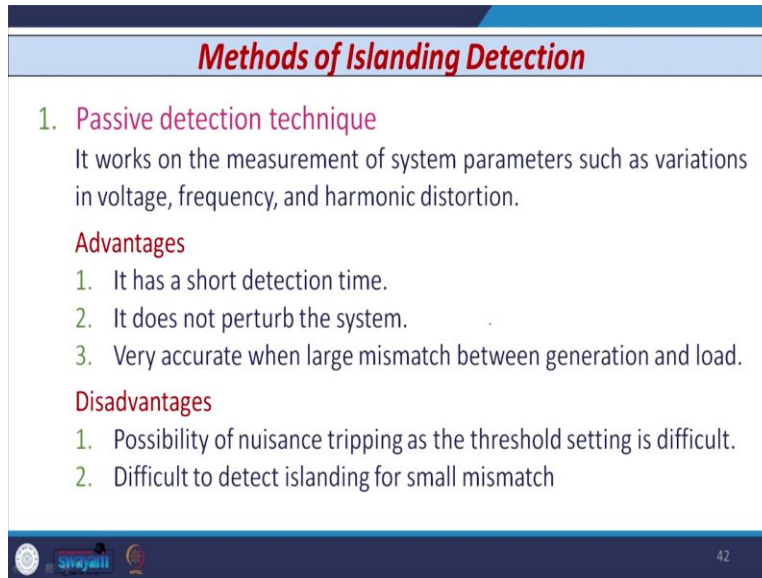
This technique is based on the measurement of system parameters of the small-scale sources, such as voltage and frequency. It is classified as follows:

1. **Passive detection technique** ✓
2. **Active detection technique** ✓
3. **Hybrid detection technique** ✓

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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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Methods of Islanding Detection

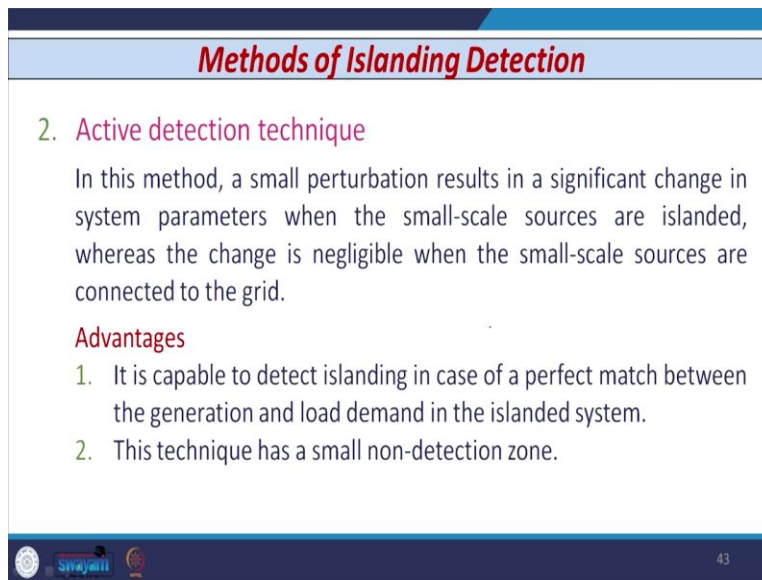
- 1. Passive detection technique**
It works on the measurement of system parameters such as variations in voltage, frequency, and harmonic distortion.
Advantages
 1. It has a short detection time.
 2. It does not perturb the system.
 3. Very accurate when large mismatch between generation and load.**Disadvantages**
 1. Possibility of nuisance tripping as the threshold setting is difficult.
 2. Difficult to detect islanding for small mismatch

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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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Methods of Islanding Detection

2. **Active detection technique**

In this method, a small perturbation results in a significant change in system parameters when the small-scale sources are islanded, whereas the change is negligible when the small-scale sources are connected to the grid.

Advantages

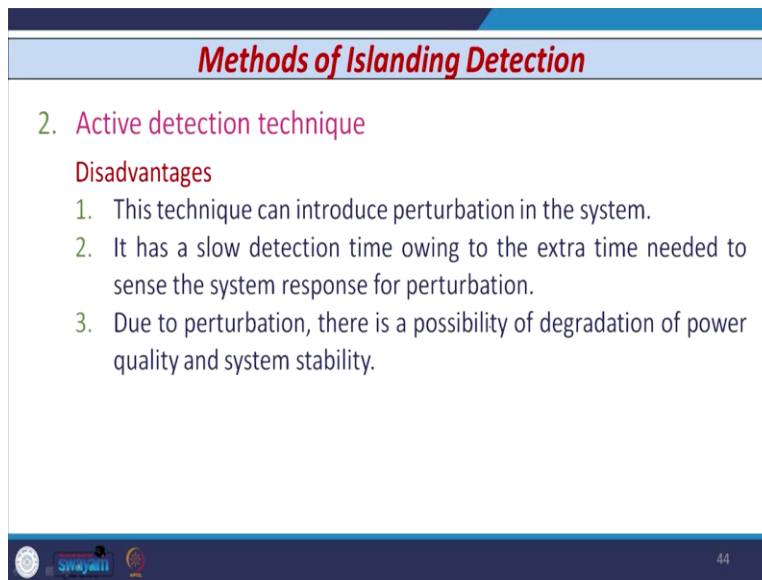
1. It is capable to detect islanding in case of a perfect match between the generation and load demand in the islanded system.
2. This technique has a small non-detection zone.

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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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Methods of Islanding Detection

2. Active detection technique

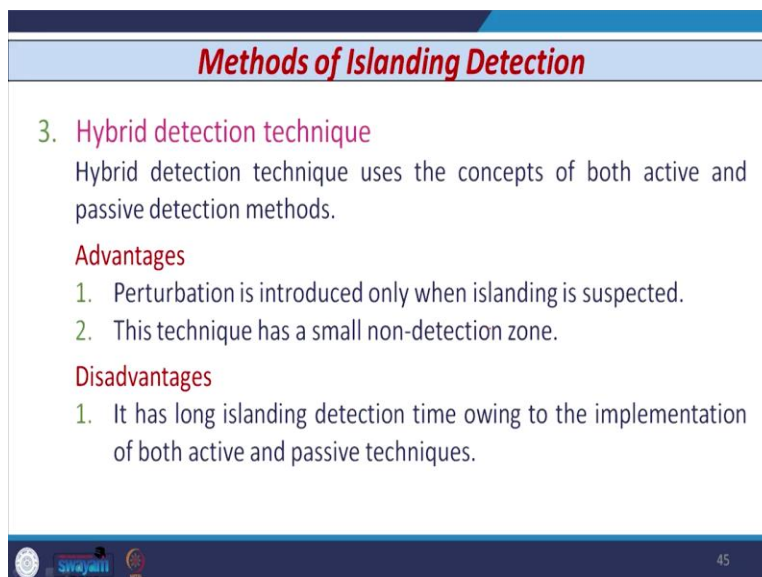
Disadvantages

1. This technique can introduce perturbation in the system.
2. It has a slow detection time owing to the extra time needed to sense the system response for perturbation.
3. Due to perturbation, there is a possibility of degradation of power quality and system stability.

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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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Methods of Islanding Detection

3. Hybrid detection technique

Hybrid detection technique uses the concepts of both active and passive detection methods.

Advantages

1. Perturbation is introduced only when islanding is suspected.
2. This technique has a small non-detection zone.

Disadvantages

1. It has long islanding detection time owing to the implementation of both active and passive techniques.

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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.