Power System Protection and Switchgear

Professor Bhuveshkumar Bhalja
Department of Electrical Engineering
Indian Institute of Technology, Roorkee

Lecture 32

Protection against Transients and Surges along with System Response to Severe Upsets-I

Okay. So in this class we will discuss regarding the protection against transient and surges and we are also going to discuss with what is the system response during severe upset situation.

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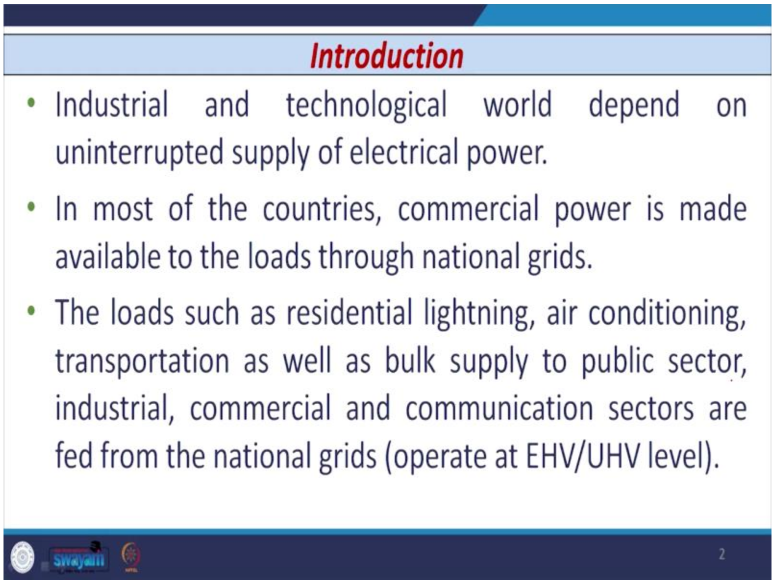

Introduction

- Industrial and technological world depend on uninterrupted supply of electrical power.
- In most of the countries, commercial power is made available to the loads through national grids.
- The loads such as residential lightning, air conditioning, transportation as well as bulk supply to public sector, industrial, commercial and communication sectors are fed from the national grids (operate at EHV/UHV level).

So we know that the industrial and technological world depends on uninterrupted electric power supply. So in most of the countries this commercial power that is made available to the loads through national grids. So loads such as residential lightening, air conditioning, transportation as well as the bulk supply to the public sector, industrial sector, commercial sector and communication sectors are again fed or provided through the national grids. And this national grids are operated through long EHV that is extra high voltage and long UHV that is ultra high voltage transmission lines.

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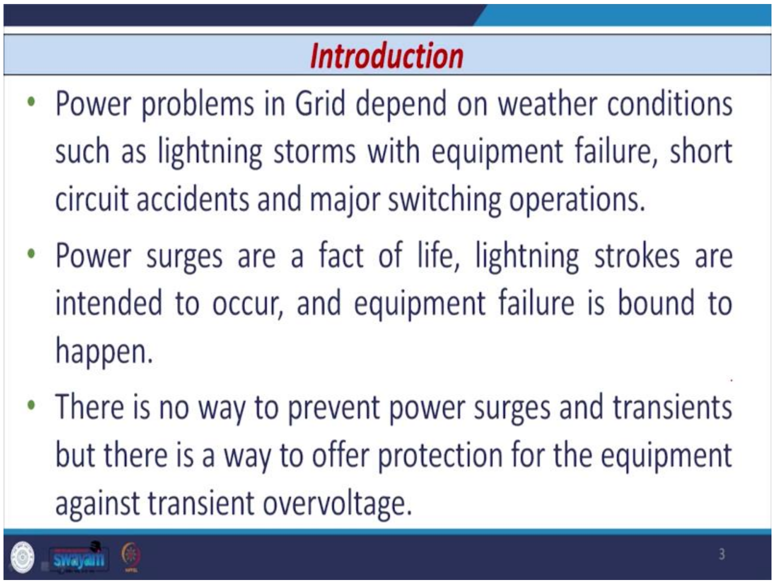

Introduction

- Power problems in Grid depend on weather conditions such as lightning storms with equipment failure, short circuit accidents and major switching operations.
- Power surges are a fact of life, lightning strokes are intended to occur, and equipment failure is bound to happen.
- There is no way to prevent power surges and transients but there is a way to offer protection for the equipment against transient overvoltage.

Now, power problems in grid that depends on weather conditions, such as lightning storms may come and because of that there is a fair possibility of equipment failure, short circuit accidents may occur and major switching operations that is also possible usually because of energization of several lines or maybe certain apparatus. For power surges are a fact of life, lightning strokes are intended to occur and equipment failures that is inevitable. So there is no way to prevent power surges and transients, but of course, there is a way to offer protection for the equipment against transient overvoltages and surges.

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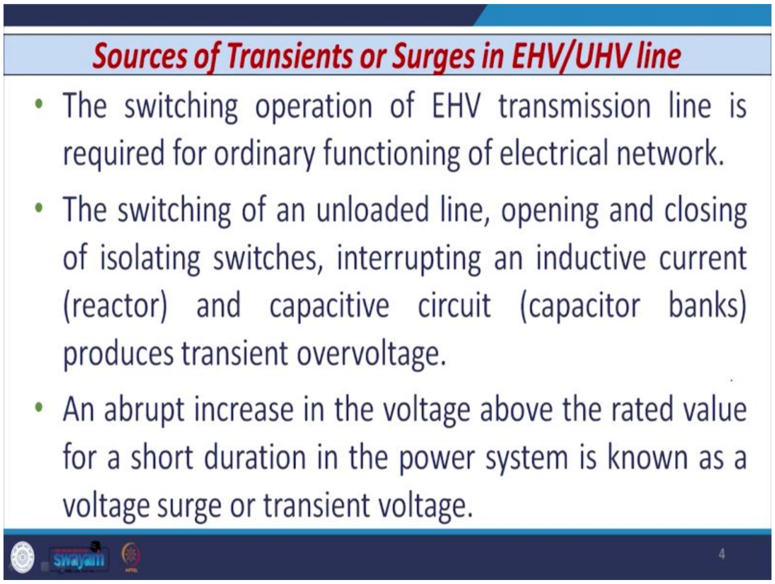

Sources of Transients or Surges in EHV/UHV line

- The switching operation of EHV transmission line is required for ordinary functioning of electrical network.
- The switching of an unloaded line, opening and closing of isolating switches, interrupting an inductive current (reactor) and capacitive circuit (capacitor banks) produces transient overvoltage.
- An abrupt increase in the voltage above the rated value for a short duration in the power system is known as a voltage surge or transient voltage.

So, let us see, what are the sources of generation of transients or surges in EHV or UHV line. So the switching operation of extra high voltage transmission line is required for ordinary functioning of electrical network. So we know that when we wish to energize the line, maybe suppose we have trip the line because of maintenance, so we have to switch off the line. So we have to switch off the circuit breakers from both ends.

Now after doing successful maintenance, if we wish to energize the line, so that the service can be restored, then we have to again energize the line from both the ends. So we have to switch on the breakers from both ends. Of course, this switching is carried out without connecting any load. So switching of an unloaded line, maybe opening or closing of isolating switches, like circuit breakers, or when circuit breaker interrupts inductive or capacitive current, then that is going to produce transient overvoltages. And abrupt increase in voltage above the rated value for a short duration in power system that is known as the voltage surge or transient voltage.

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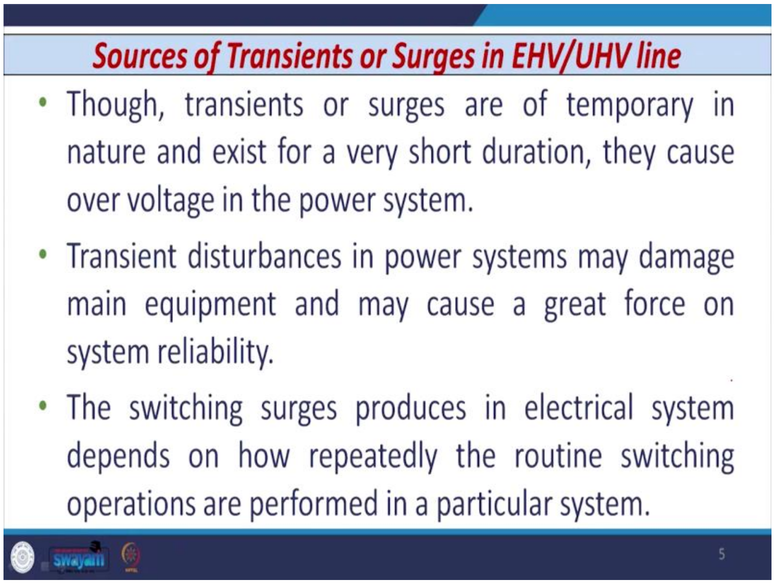

Sources of Transients or Surges in EHV/UHV line

- Though, transients or surges are of temporary in nature and exist for a very short duration, they cause over voltage in the power system.
- Transient disturbances in power systems may damage main equipment and may cause a great force on system reliability.
- The switching surges produces in electrical system depends on how repeatedly the routine switching operations are performed in a particular system.

Though transient or surges are temporary in nature and they are for short duration, they cause overvoltage in the system. So transient disturbances in power systems may damage the main equipment and sometimes they may cause a great force on system reliability. The switching surges produces in electrical system that depend on how repeatedly the routine switching operations of maybe lines or apparatus, that is to be carried out or performed.

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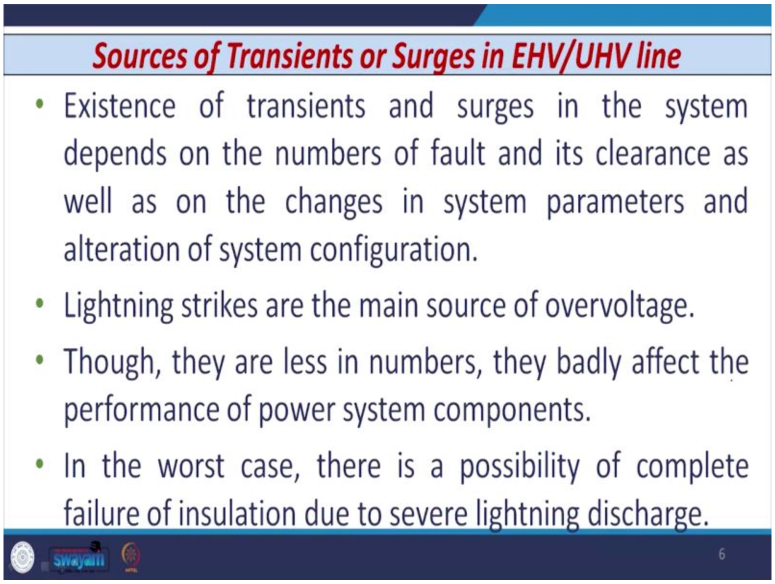

Sources of Transients or Surges in EHV/UHV line

- Existence of transients and surges in the system depends on the numbers of fault and its clearance as well as on the changes in system parameters and alteration of system configuration.
- Lightning strikes are the main source of overvoltage.
- Though, they are less in numbers, they badly affect the performance of power system components.
- In the worst case, there is a possibility of complete failure of insulation due to severe lightning discharge.

So, existence of transients and surges in the system that depends on the number of fault and its clearance as well as the changes in system parameters and alteration of system configuration. So, lightning strikes are the main source of overvoltages. However, switching surges are also there, and because of that voltage can increase. Though these lightning surges are less in numbers, they badly affect the performance of power system components. In the worst case, there is a possibility of complete failure of insulation due to severe lightening discharge.

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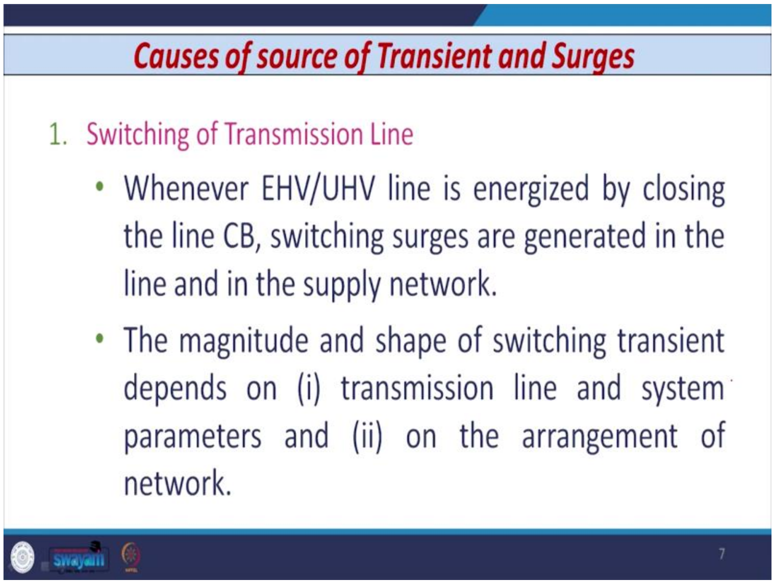

Causes of source of Transient and Surges

1. Switching of Transmission Line
    - Whenever EHV/UHV line is energized by closing the line CB, switching surges are generated in the line and in the supply network.
    - The magnitude and shape of switching transient depends on (i) transmission line and system parameters and (ii) on the arrangement of network.

So, let us see, whenever we switch on the transmission line, how the voltage surge occurs and what is its effect. So, when we consider the EHV and UHV line and when it, this lines are energized by closing the line circuit breaker from local as well as remote end, the switching surges are generated in the line and in the supply network. The magnitude and shape of the switching transient that depends on transmission line and system parameters and the arrangement of network.

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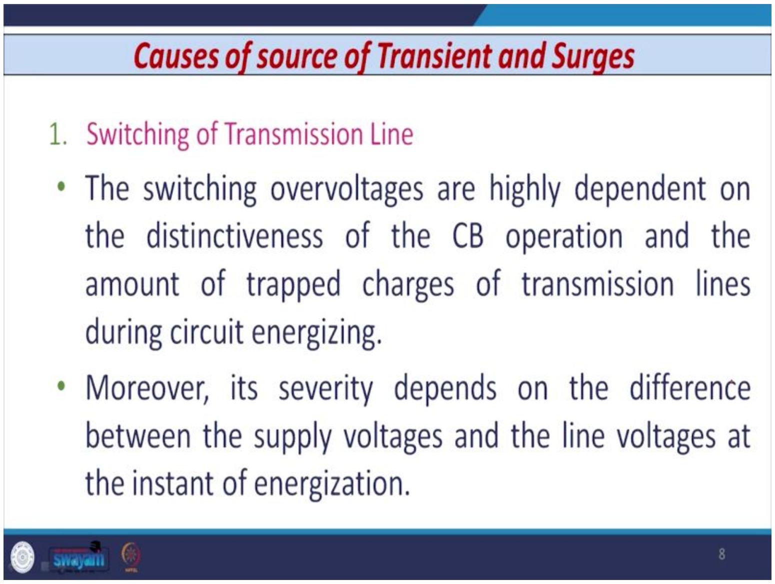

Causes of source of Transient and Surges

1. Switching of Transmission Line

- The switching overvoltages are highly dependent on the distinctiveness of the CB operation and the amount of trapped charges of transmission lines during circuit energizing.
- Moreover, its severity depends on the difference between the supply voltages and the line voltages at the instant of energization.

The switching overvoltages are highly dependent on the distinctiveness of the circuit breaker operation and the amount of trap charge of transmission lines during the energizing. So, when you energize this transmission line, before first energization, suppose the line is already energized and then it is taken in maintenance, so it is switched off, now again you are switching on the line, so there must be some trap charge. So that is also going to affect the what is the voltages or transient overvoltages that appear that is also going to decide by the trap charge.

Moreover, its severity depends on the difference between the supply voltages and the line voltages at the instant of energization.

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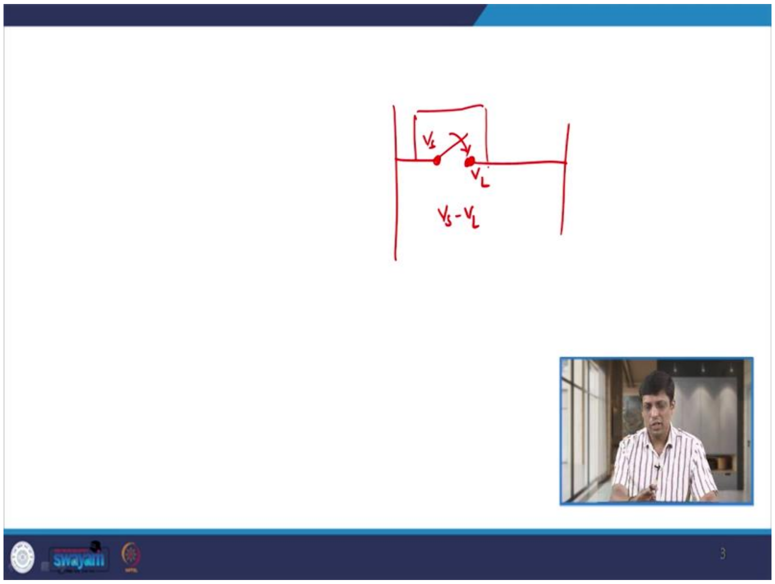

So that means when you energize the line, suppose for example, we have let us say there is a breaker here, and suppose, we wish to energize this line by closing this circuit breaker. So this, if I consider this point, then this voltage is your supply voltage and this voltage is your line voltages. So what is the difference between this two voltages that is going to decide how much voltage or transient overvoltage that is going to appear.

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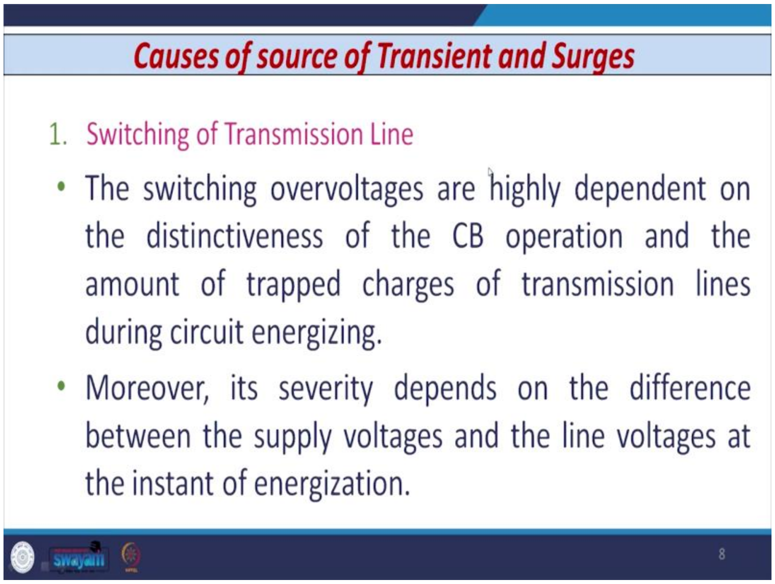

Causes of source of Transient and Surges

1. Switching of Transmission Line

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So its severity also depends on the difference of supply voltage and line voltages at the instant of energization.

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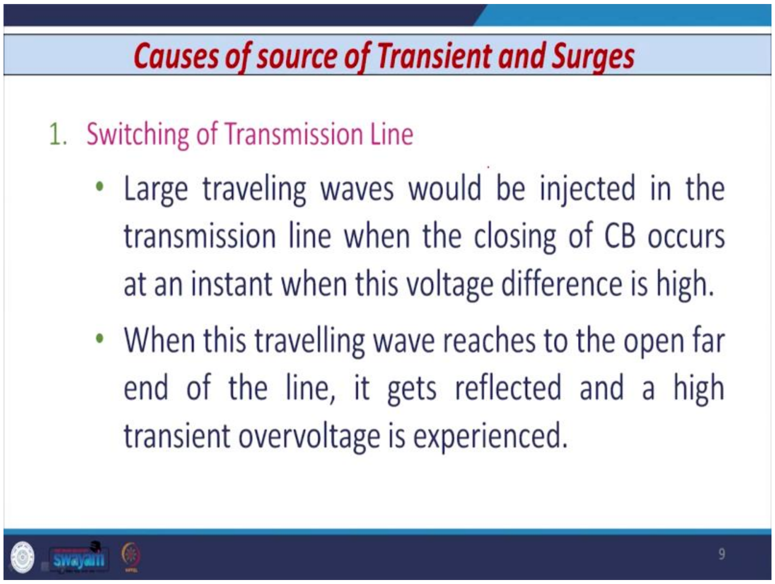

Causes of source of Transient and Surges

1. Switching of Transmission Line
    - Large traveling waves would be injected in the transmission line when the closing of CB occurs at an instant when this voltage difference is high.
    - When this travelling wave reaches to the open far end of the line, it gets reflected and a high transient overvoltage is experienced.

Large traveling waves that would be injected in the transmission line when the closing of circuit breaker occurs at an instant, when this voltage difference is high. So the difference between the Vs and Vl supply voltage and line voltage is high and at that time if you energize the line, then the traveling waves that would be also that is significant. When this traveling wave reaches to the open end or far end of the line it gets reflected and a high transient overvoltage is that is experienced.

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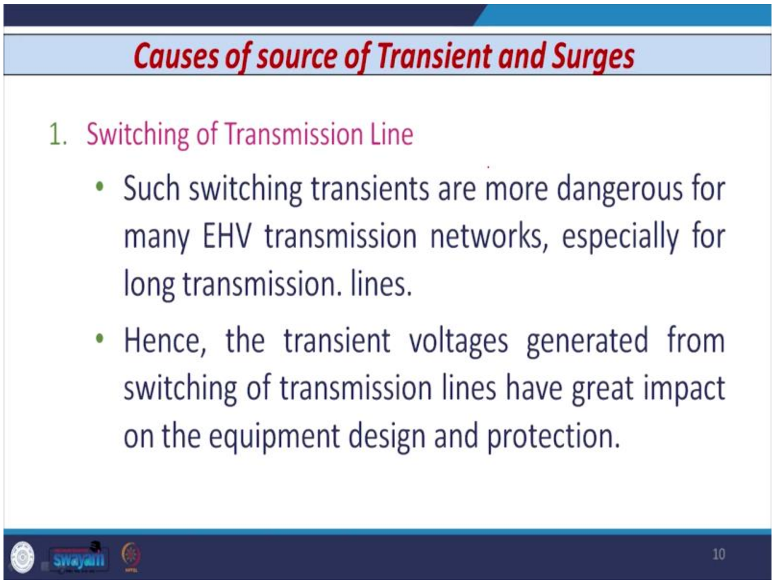

Causes of source of Transient and Surges

1. Switching of Transmission Line
    - Such switching transients are more dangerous for many EHV transmission networks, especially for long transmission. lines.
    - Hence, the transient voltages generated from switching of transmission lines have great impact on the equipment design and protection.

Such switching transients are more dangerous for many UHV lines, especially for long lines. Hence, transient overvoltages generated from switching of transmission lines have great impact on the equipment design and the protection.

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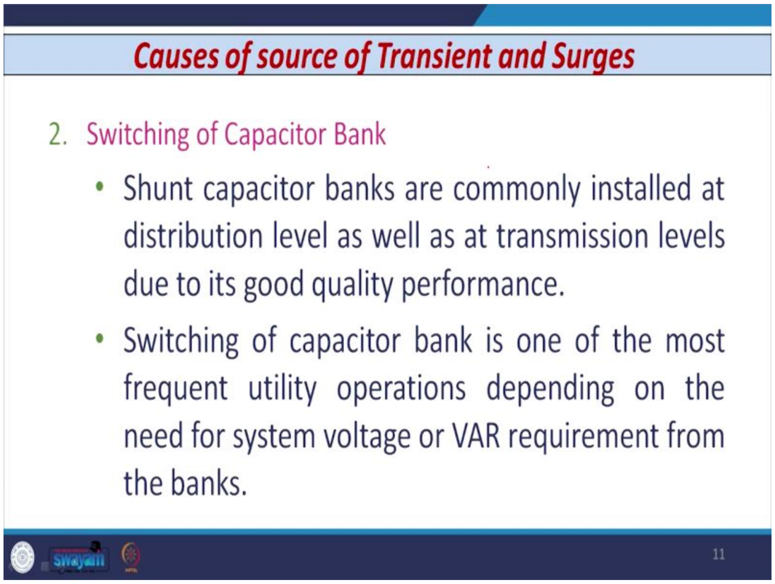

Causes of source of Transient and Surges

2. Switching of Capacitor Bank
    - Shunt capacitor banks are commonly installed at distribution level as well as at transmission levels due to its good quality performance.
    - Switching of capacitor bank is one of the most frequent utility operations depending on the need for system voltage or VAR requirement from the banks.

So, the, let us consider the second point that is the switching of capacitor bank. So we know that shunt capacitor banks are commonly installed at distribution as well as transmission level. So at distribution level, the shunt capacitor banks are used for power factor improvement, whereas at transmission level, it can be used maybe for the system voltage requirement or the supply of VAR requirement. So switching of capacitor bank is one of the most frequent utility operations and that depends on the voltage requirement as well as VAR requirement.

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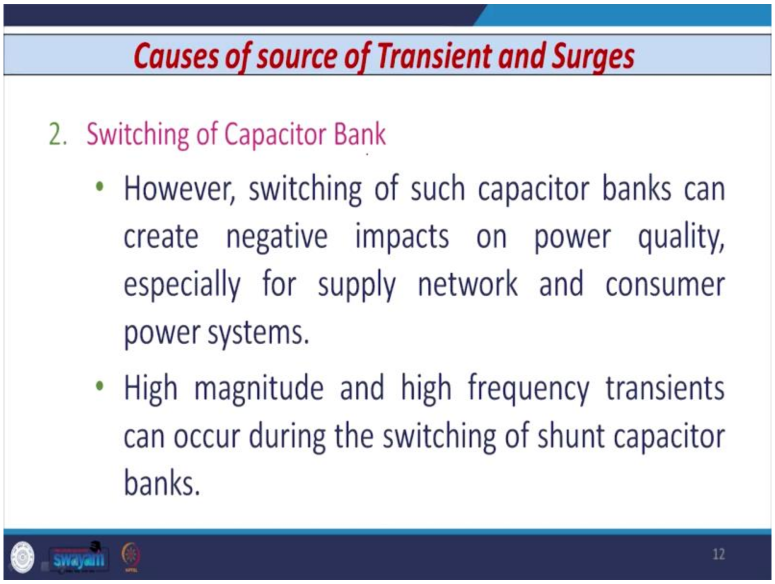

Causes of source of Transient and Surges

2. Switching of Capacitor Bank
   - However, switching of such capacitor banks can create negative impacts on power quality, especially for supply network and consumer power systems.
   - High magnitude and high frequency transients can occur during the switching of shunt capacitor banks.

However, switching of such capacitor banks can create negative impact as far as the power quality is concerned and the supply network and consumer power system is concerned. High magnitude and high frequency transients can occur during the switching of shunt capacitor banks.

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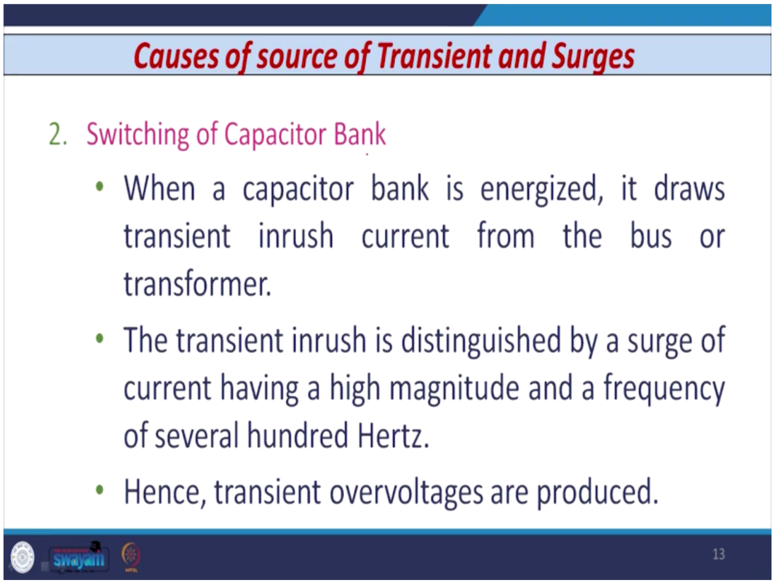

Causes of source of Transient and Surges

2. Switching of Capacitor Bank
    - When a capacitor bank is energized, it draws transient inrush current from the bus or transformer.
    - The transient inrush is distinguished by a surge of current having a high magnitude and a frequency of several hundred Hertz.
    - Hence, transient overvoltages are produced.

Whenever a capacitor bank is energized, it draws a transient current that is known as transient inrush current from the bus or from the transformer. The transient inrush that is distinguished by a surge of current having high magnitude and high frequency that is of several hundred hertz. Hence, transient overvoltages are produced.

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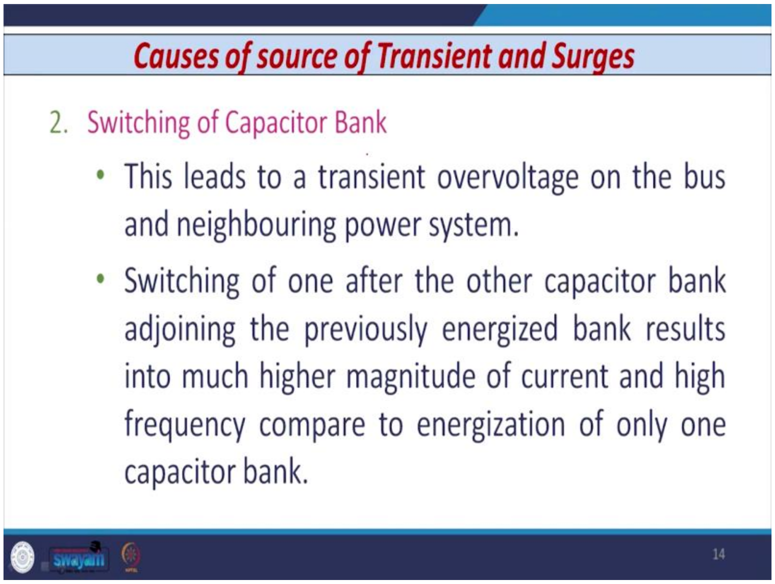

Causes of source of Transient and Surges

2. Switching of Capacitor Bank
    - This leads to a transient overvoltage on the bus and neighbouring power system.
    - Switching of one after the other capacitor bank adjoining the previously energized bank results into much higher magnitude of current and high frequency compare to energization of only one capacitor bank.

So, switching of one after the other capacitor adjoining the previously energized, suppose we have one capacitor bank and along with that we have another capacitor bank, so when one capacitor bank is already energized and when you energize the another capacitor bank, then also the magnitude of current and the frequency that is also very high and because of that whatever transient overvoltage is produced that is severe than the only single capacitor bank that is energized.

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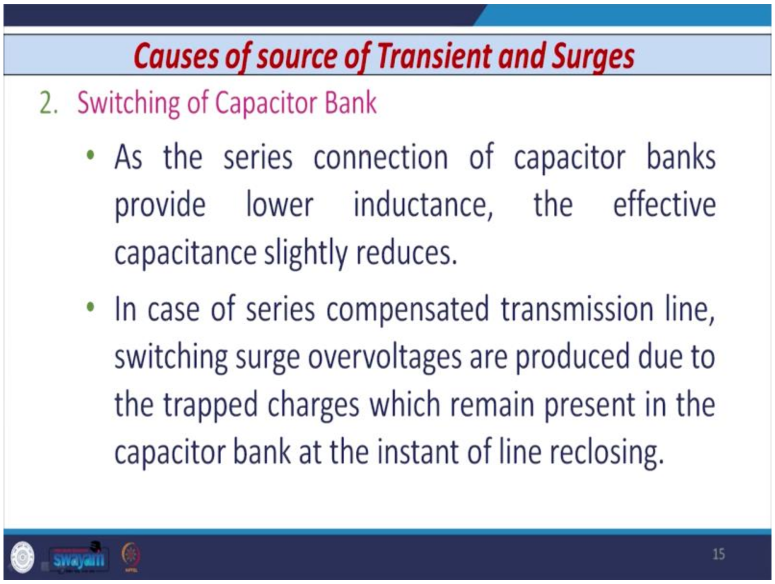

Causes of source of Transient and Surges

2. Switching of Capacitor Bank
    - As the series connection of capacitor banks provide lower inductance, the effective capacitance slightly reduces.
    - In case of series compensated transmission line, switching surge overvoltages are produced due to the trapped charges which remain present in the capacitor bank at the instant of line reclosing.

So, as the series connection of capacitor banks provide lower inductance, the effective capacitance slightly reduces. So in case of series compensated transmission line, switching surge overvoltages are produced due to trapped charges then that remain present in the capacitor bank at the instant of line reclosing.

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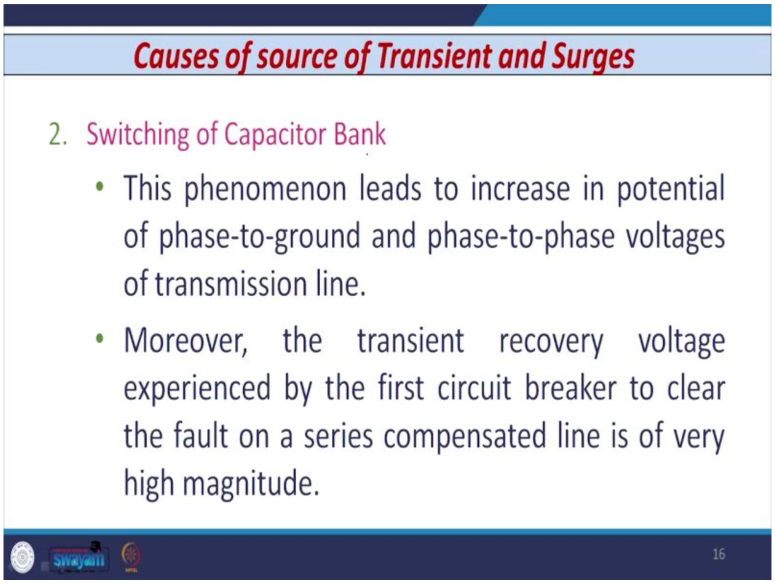

Causes of source of Transient and Surges

2. Switching of Capacitor Bank
   - This phenomenon leads to increase in potential of phase-to-ground and phase-to-phase voltages of transmission line.
   - Moreover, the transient recovery voltage experienced by the first circuit breaker to clear the fault on a series compensated line is of very high magnitude.

So, this phenomenon leads to increase in potential of phase-to-ground as well as phase-to-phase voltages of the transmission line. Moreover, the transient recovery voltage that is known as TRV voltage experienced by first circuit breaker to clear the fault on series compensated line that is also of very high magnitude.

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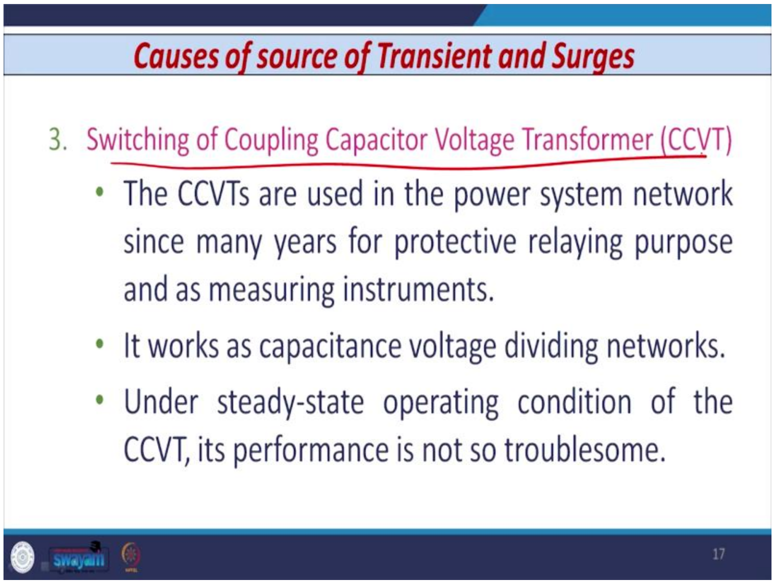

Causes of source of Transient and Surges

3. Switching of Coupling Capacitor Voltage Transformer (CCVT)
   - The CCVTs are used in the power system network since many years for protective relaying purpose and as measuring instruments.
   - It works as capacitance voltage dividing networks.
   - Under steady-state operating condition of the CCVT, its performance is not so troublesome.

So, let us consider the third point that is known as the switching of coupling capacitor voltage transformer that is known as CCVT. So, we know that the CCVTs are used in power system network since many years for protective relaying application purpose and as well as for measurement purpose. So it works as capacitance voltage dividing networks and under steady-state operating condition of the CCVT, its performance is not so troublesome.

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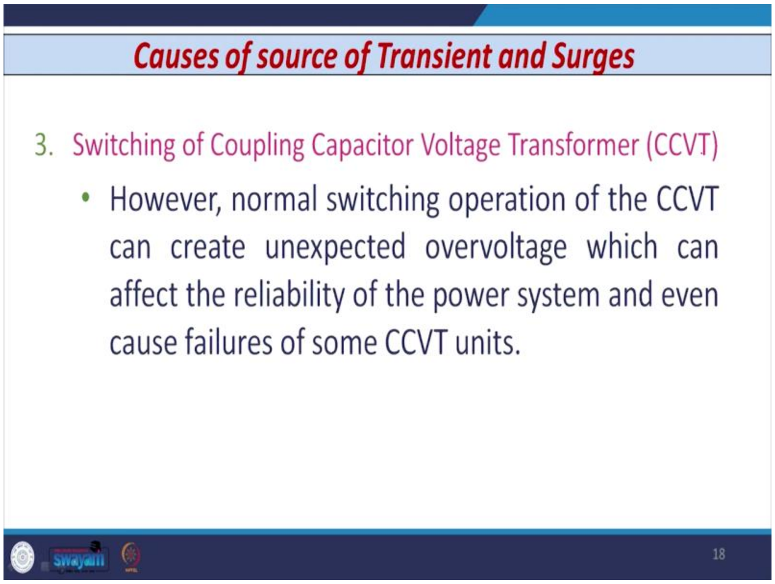

Causes of source of Transient and Surges

3. Switching of Coupling Capacitor Voltage Transformer (CCVT)
   - However, normal switching operation of the CCVT can create unexpected overvoltage which can affect the reliability of the power system and even cause failures of some CCVT units.

However, normal switching operation of the coupling capacitor voltage transformer that is CCVT can create unexpected overvoltage, which can affect the reliability of power system and even sometimes cause failures of one or multiple CCVT units.

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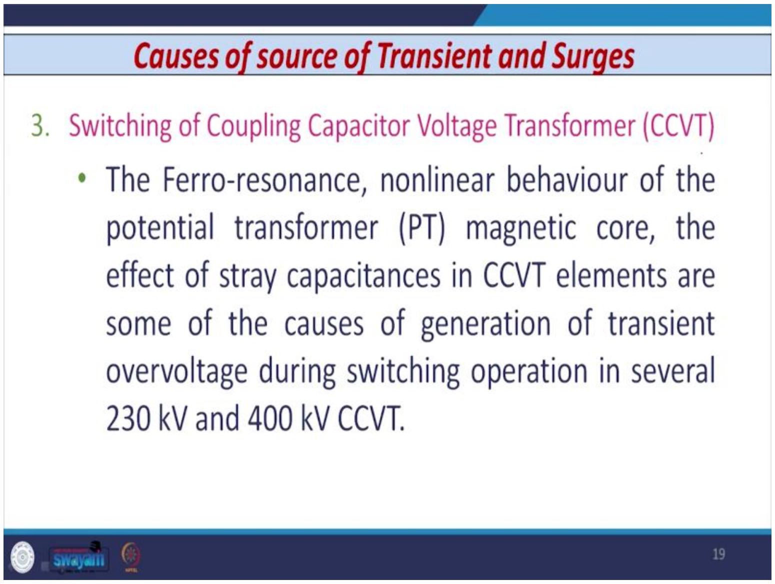

Causes of source of Transient and Surges

3. Switching of Coupling Capacitor Voltage Transformer (CCVT)
   - The Ferro-resonance, nonlinear behaviour of the potential transformer (PT) magnetic core, the effect of stray capacitances in CCVT elements are some of the causes of generation of transient overvoltage during switching operation in several 230 kV and 400 kV CCVT.

So, the ferro-resonance in the CCVT, nonlinear behavior of the potential transformer magnetic core, the effect of stray capacitance in CCVT elements are some of the causes of generation of transient overvoltage during switching operation in several maybe 220kV or 400kV CCVT.

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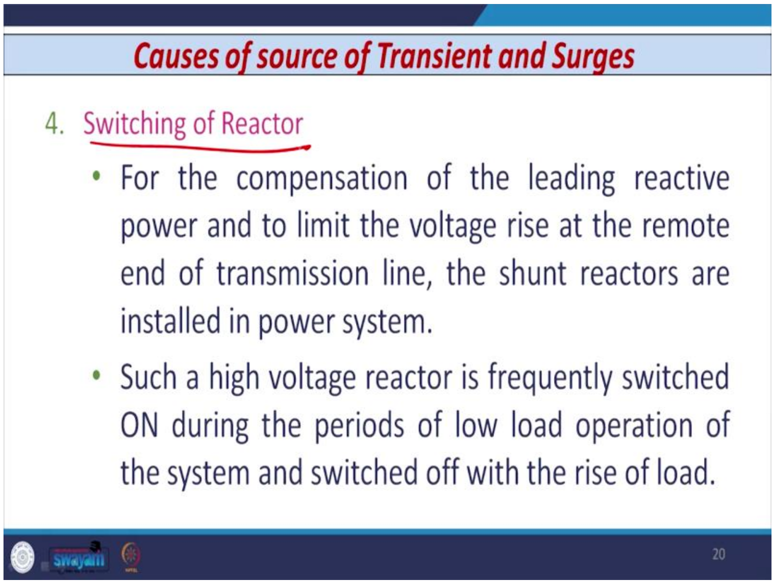

Causes of source of Transient and Surges

4. Switching of Reactor
   - For the compensation of the leading reactive power and to limit the voltage rise at the remote end of transmission line, the shunt reactors are installed in power system.
   - Such a high voltage reactor is frequently switched ON during the periods of low load operation of the system and switched off with the rise of load.

The fourth point that is the switching of reactor and because of this also the transient or surges that may generate. For the compensation of leading reactive power and so to limit the voltage rise at the remote end of the line shunt reactors are installed in the power system network. Such a high voltage reactor is frequently switched on and switched off during the periods of low load operation of the system and it is switched off when the load increases.

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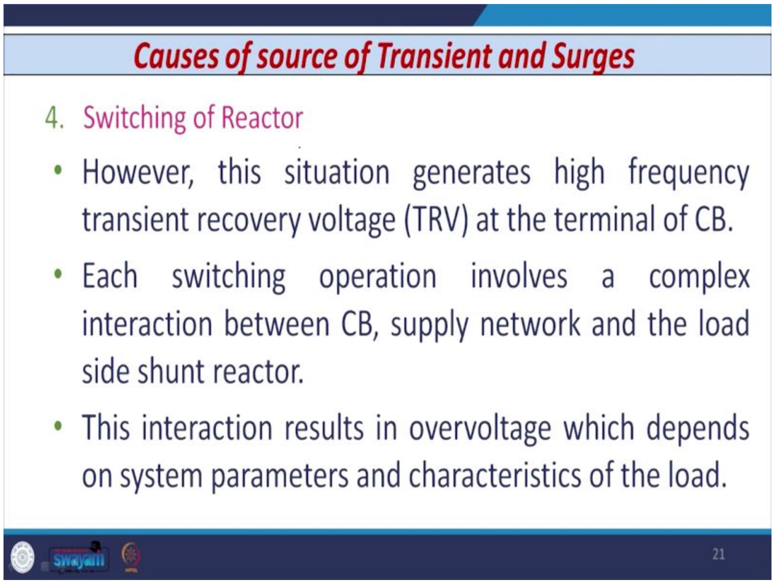

Causes of source of Transient and Surges

4. Switching of Reactor

- However, this situation generates high frequency transient recovery voltage (TRV) at the terminal of CB.
- Each switching operation involves a complex interaction between CB, supply network and the load side shunt reactor.
- This interaction results in overvoltage which depends on system parameters and characteristics of the load.

However, this situation generates high frequency transient recovery voltage at the terminal of circuit breaker. Each switching operation involves a complex interaction between circuit breaker, supply network and the load side shunt reactor. So this interaction results in overvoltage, which depends on system parameters as well as the characteristic of the load.

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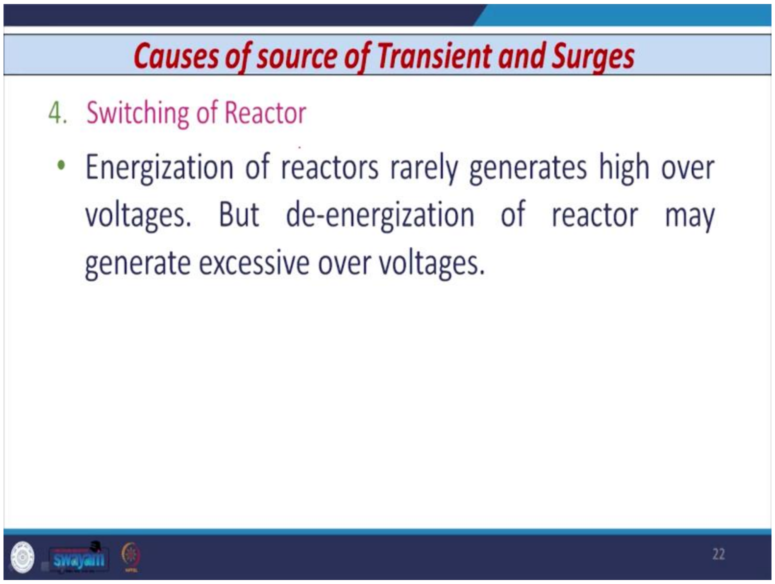

Causes of source of Transient and Surges

4. Switching of Reactor

- Energization of reactors rarely generates high over voltages. But de-energization of reactor may generate excessive over voltages.

So, energization of reactors rarely generates high overvoltages, but when you de-energize the reactor, then that may generate excessive overvoltages.

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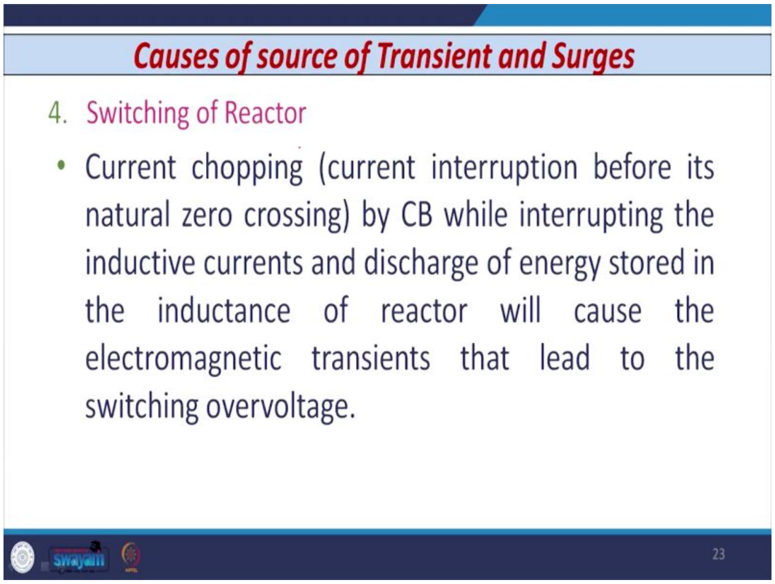

Causes of source of Transient and Surges

4. Switching of Reactor

- Current chopping (current interruption before its natural zero crossing) by CB while interrupting the inductive currents and discharge of energy stored in the inductance of reactor will cause the electromagnetic transients that lead to the switching overvoltage.

Current chopping, maybe current interruption before the natural current zero comes by the circuit breaker, while interrupting the small inductive current and discharge of energy stored in the inductance of the reactor that will cause the electromagnetic transients that lead to the switching overvoltages.

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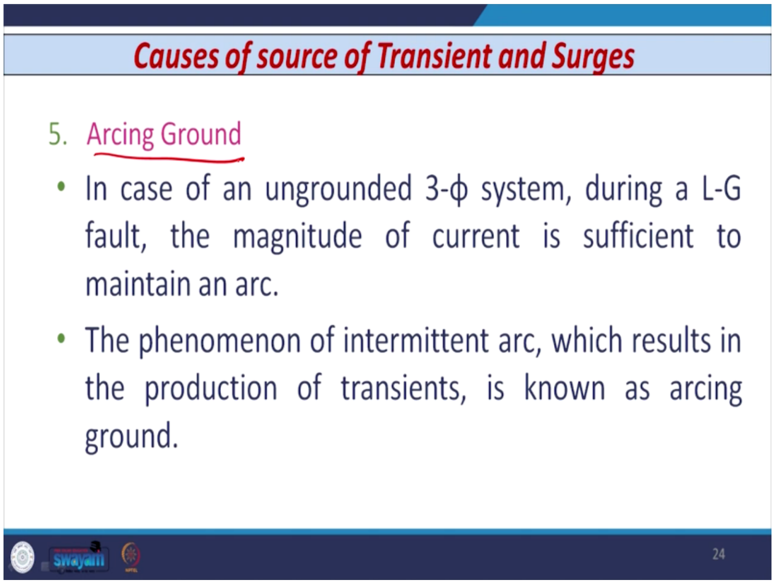

Causes of source of Transient and Surges

5. Arcing Ground

- In case of an ungrounded 3-ϕ system, during a L-G fault, the magnitude of current is sufficient to maintain an arc.
- The phenomenon of intermittent arc, which results in the production of transients, is known as arcing ground.

The fifth point that is responsible for generation of transients and surges that is arcing ground phenomenon. So, in case of an ungrounded three phase system during a single line to ground fault, the magnitude of current is sufficient to maintain the arc. The phenomenon of intermittent arc, which results in the production of transient that is known as arcing ground. So whenever the arc that is intermittently produced that is known as the arcing ground.

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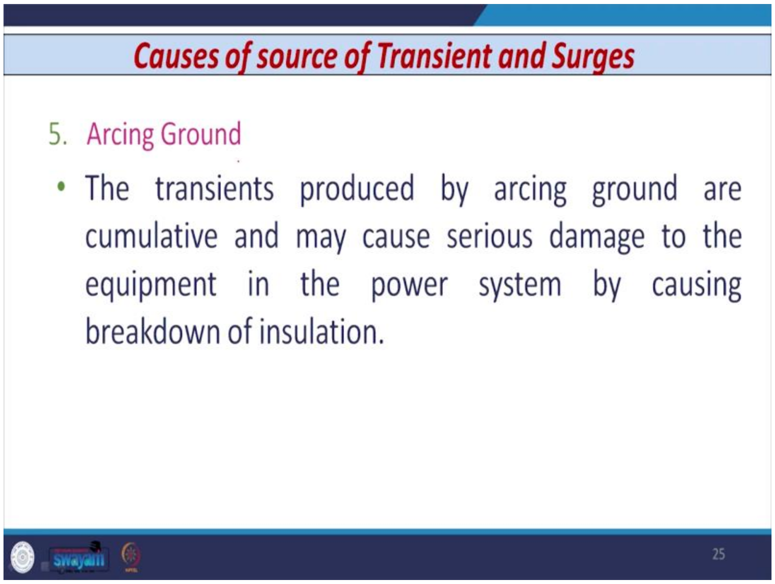

Causes of source of Transient and Surges

5. Arcing Ground

- The transients produced by arcing ground are cumulative and may cause serious damage to the equipment in the power system by causing breakdown of insulation.

The transients produced by arcing ground are cumulative in nature and may cause the severe damage to the equipment in the power system by causing breakdown of insulation.

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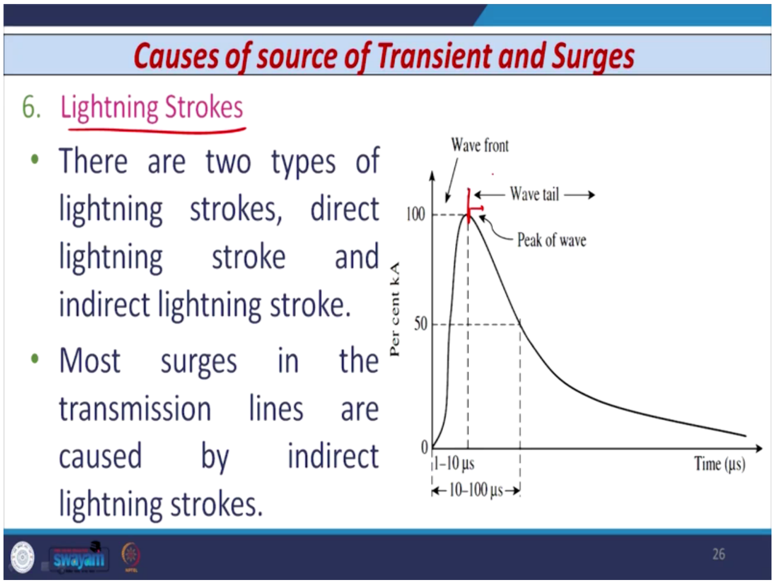

Causes of source of Transient and Surges

6. Lightning Strokes

- There are two types of lightning strokes, direct lightning stroke and indirect lightning stroke.
- Most surges in the transmission lines are caused by indirect lightning strokes.

The next point that is known as the lightening strokes. So this is also responsible for the generation of transient and surges. So there are two types of lightening strokes that one is known as direct lightening stroke and other is known as the indirect lightning stroke. Most surges in the transmission lines are caused by indirect lightning strokes. So, you can see that there is a wave form given here and on this wave form is the current percent kilo ampere versus the time in microsecond. And you can see that the there is a wave shape. And up to this point, you can see this is known as the wave front of the wave. And on the other side of this point, the remaining that is the wave tail of the wave shape. And this is the peak of the wave. And you can see the time is also mentioned, the wave front that is of 1 to 10 microsecond, whereas wave tail is beyond 10 microsecond. And whenever lightning strike comes, then such type of wave shape exists.

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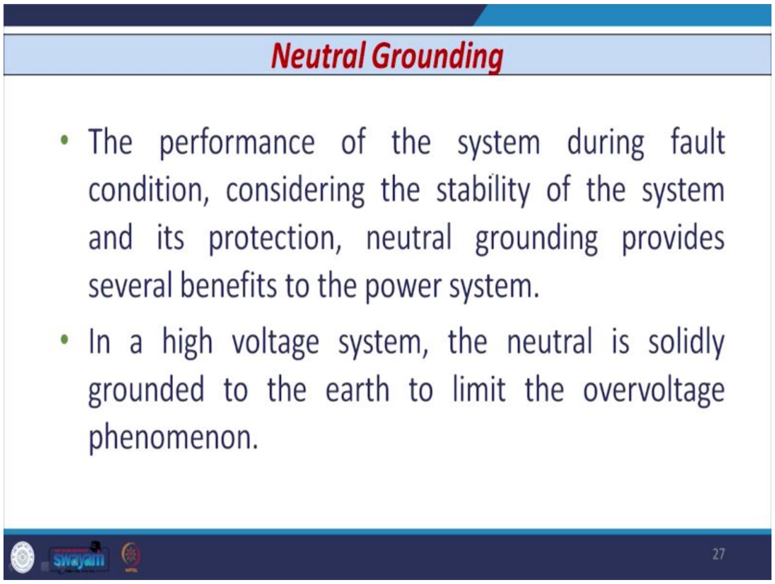

Neutral Grounding

- The performance of the system during fault condition, considering the stability of the system and its protection, neutral grounding provides several benefits to the power system.
- In a high voltage system, the neutral is solidly grounded to the earth to limit the overvoltage phenomenon.

Now, the next concept that is known as the neutral grounding. We know that the performance of the system during fault condition considering the stability of the system and its protection, neutral grounding provides several benefits to the power system. So, that means, whenever we use the generator, whenever we use any other devices, whether the neutral of the generator or neutral of the any other apparatus is grounded or not that concept is known as the neutral grounding concept. In a high voltage system, the neutral is solidly grounded to the earth and just to limit the overvoltage phenomenon.

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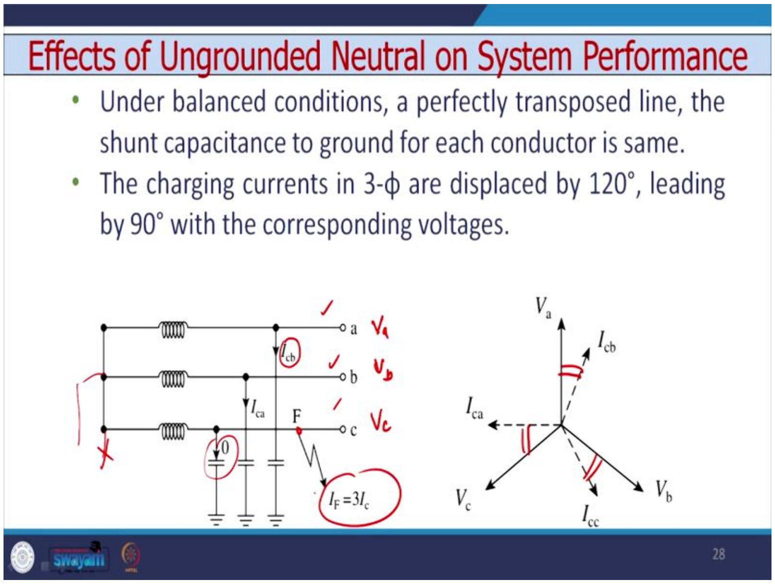

Effects of Ungrounded Neutral on System Performance

- Under balanced conditions, a perfectly transposed line, the shunt capacitance to ground for each conductor is same.
- The charging currents in 3-ϕ are displaced by 120°, leading by 90° with the corresponding voltages.

So, let us consider different cases and let us see what is the effect of whether the neutral is grounded or ungrounded. So, let us consider the first case effects of ungrounded neutral on system performance. So, under balanced condition, a perfectly transpose line, the shunt capacitance to ground for each conductor is same. So the charging currents in three phase are displaced by 120 degree, leading by 90 degree with the corresponding voltages.

So you can see that I have shown here one system with three conductors a, b, c and the neutral of this point that is not grounded, it is not connected, this is not connected, so it is not there. You can see that the voltages of this a, b, c phase are Va, Vb and Vc and this are vectorially plotted as Va, Vb and Vc, all three are 120 degree apart. The three currents that is the in a phase, b phase and c phase that is known as the Icb, Ica and the third point where the fault occurs, this current that is zero, so you can see that this issue represented with capacitance. So the current that is Ica and Icb that also I have shown here that is Icb, Ica and Icc that is also 120 degree apart and there is an angle difference between the Va and Icb, Vb and Icc and this also there.

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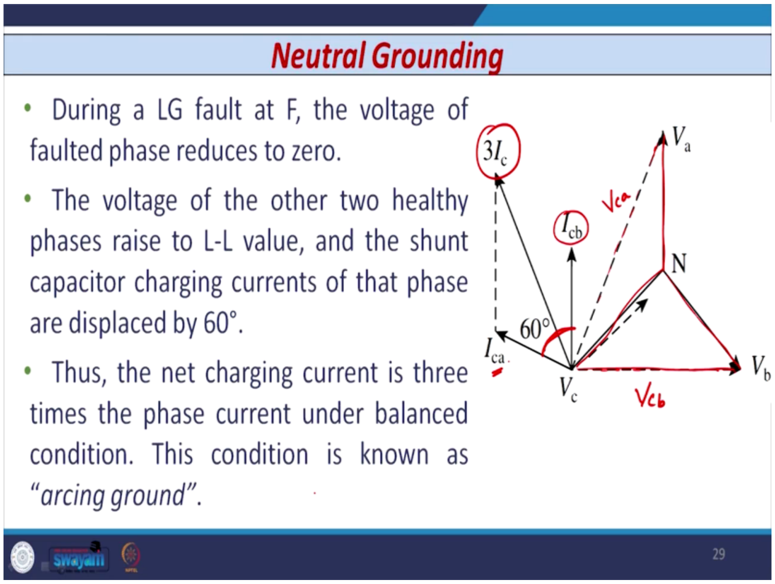
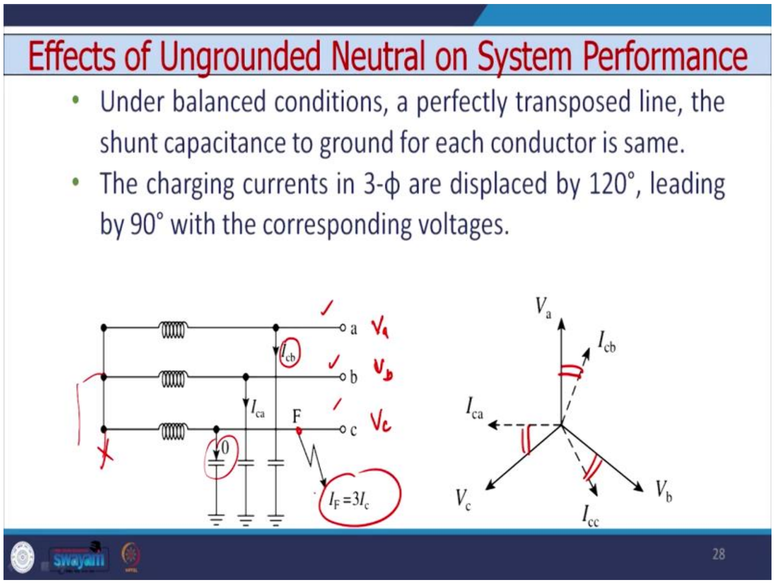


Neutral Grounding

- During a LG fault at F, the voltage of faulted phase reduces to zero.
- The voltage of the other two healthy phases raise to L-L value, and the shunt capacitor charging currents of that phase are displaced by 60°.
- Thus, the net charging current is three times the phase current under balanced condition. This condition is known as *"arcing ground"*.



Effects of Ungrounded Neutral on System Performance

- Under balanced conditions, a perfectly transposed line, the shunt capacitance to ground for each conductor is same.
- The charging currents in 3-ϕ are displaced by 120°, leading by 90° with the corresponding voltages.

Now during a single line to ground fault at this point that is at point F, the voltage of the faulted phase reduces to zero. So obviously whenever fault occurs here, this phase voltage c phase voltage that reduces and that becomes almost near to zero. The voltage of the other two healthy phases that increases and that will reach to the line to line voltages and shunt capacitor charging currents of that phase are displaced by 60 degree.

So, you can see here in vector diagram, the Va, Vb and Vc are shown here, then I have to draw the line to line, these are the phase voltages. So if I can, just calculate the line to line voltages, you have to connect with, Va with Vc. So you have the one voltages I have shown this dotted line here and the other with Vc to Vb.

So you can see that the current that is the Icb current that is here you can see this current Icb current from a phase to ground, this current leads by the voltage, this voltage that is Vcb by an angle 90 degree. Similarly, the other current that is Ica that leads the voltages that is the Vca this voltage by again 90 degree. And so the angle between Ica and Icb this angle that is 60 degree and if you take again the parallelogram then you will get this current that is 3Ic, so that 3Ic current that is going to flow through the fault and that is the fault current. Thus, the net charging current that is three times the phase current under the balanced condition and this condition is known as arcing ground condition.

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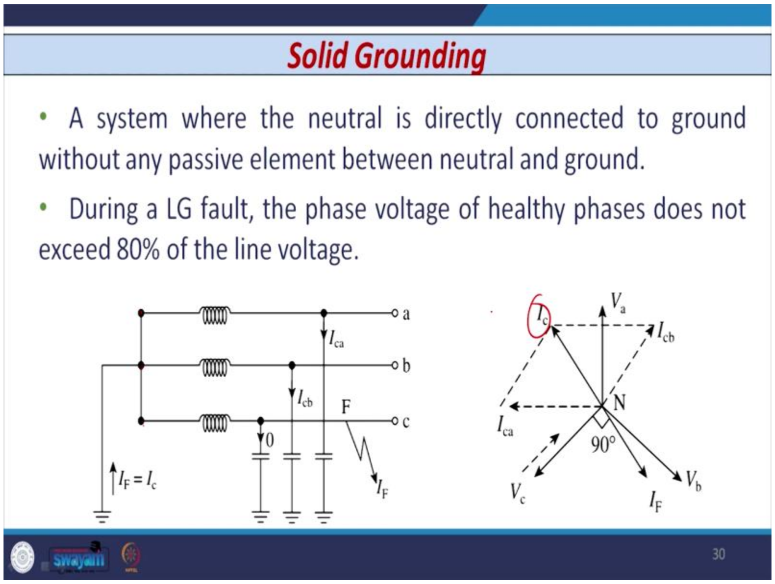

Solid Grounding

- A system where the neutral is directly connected to ground without any passive element between neutral and ground.
- During a LG fault, the phase voltage of healthy phases does not exceed 80% of the line voltage.

Now, if I consider the solid grounding that means this point is directly connected to the earth, these three points that is directly connected to the earth. So a system where the neutral is directly connected to the ground without any resistor or reactor, than during a single line to ground fault, the phase voltage of healthy phases does not exceed the 80% of the line voltage. So, that means, if you solidly ground the system then the phase voltage of other healthy phases in which fault is not there, those voltages are not going to increase up to line voltage, but it will restrict up to 80% of the line voltage.

So, again you can see the same vector diagram Va, Vb, Vc, all our 120 degree apart and then I have plotted the Ica and Icb as I shown here in this vector diagram and after getting parallelogram you will get the current Ic.

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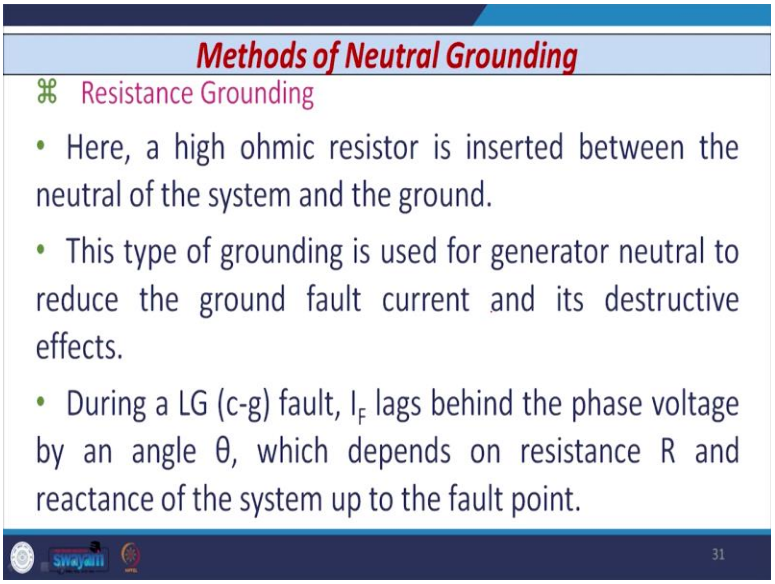

Methods of Neutral Grounding

⌘ Resistance Grounding

- Here, a high ohmic resistor is inserted between the neutral of the system and the ground.
- This type of grounding is used for generator neutral to reduce the ground fault current and its destructive effects.
- During a LG (c-g) fault, I_F lags behind the phase voltage by an angle θ, which depends on resistance R and reactance of the system up to the fault point.

Now, let us consider the resistance grounding. So, here in case of resistor grounding, high ohmic resistor is inserted between the neutral of the system and the ground. So this type of grounding is used in generator neutral to reduce the magnitude of ground fault current and its destructive effect. So, during a single line to ground fault, say c phase to ground fault, again the same condition we take, the fault current IF lags behind the phase voltage by an angle theta, which depends on the value of resistor connected the is R and the reactance of the system up to the fault point.

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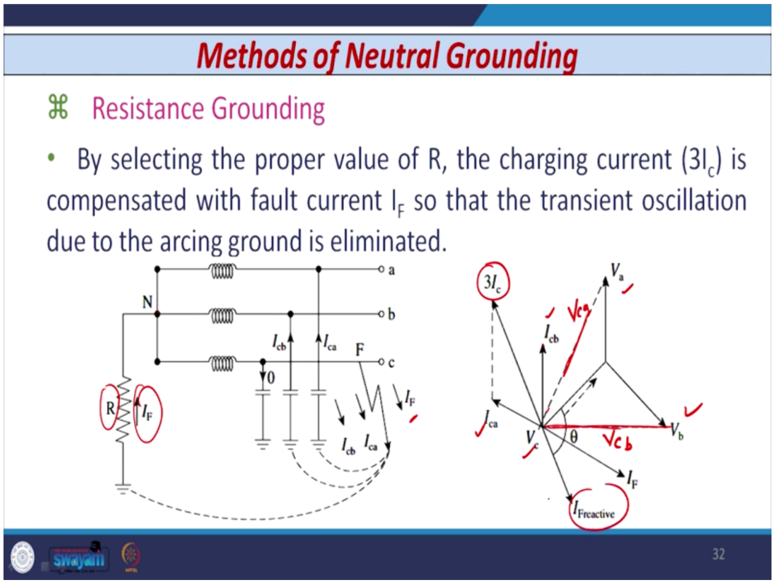
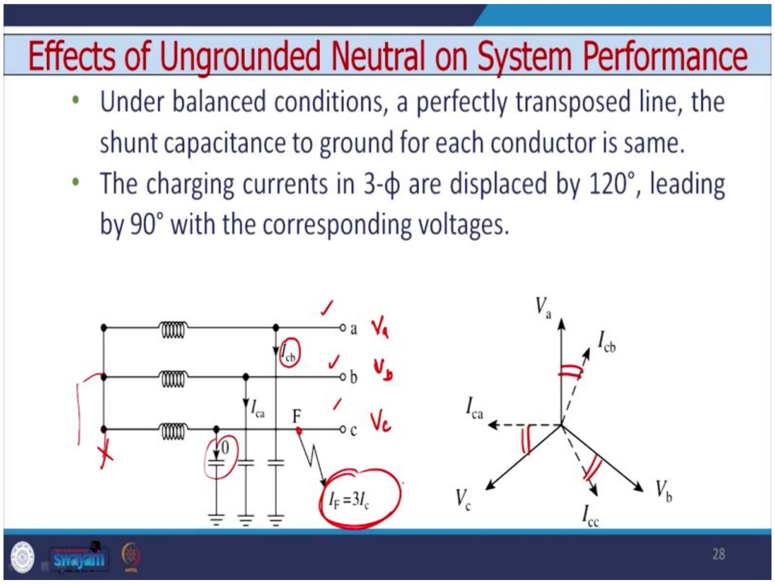


Methods of Neutral Grounding

⌘ Resistance Grounding

- By selecting the proper value of R, the charging current ($3I_c$) is compensated with fault current I_F so that the transient oscillation due to the arcing ground is eliminated.



Effects of Ungrounded Neutral on System Performance

- Under balanced conditions, a perfectly transposed line, the shunt capacitance to ground for each conductor is same.
- The charging currents in 3-ϕ are displaced by 120°, leading by 90° with the corresponding voltages.

So if I consider the resistance grounding, then by selecting the proper value of R, the charging current which is going to flow through the IF which is equal to 3 times the Ic that is compensated with fault current IF, so that the transient oscillation due to arcing ground that is eliminated. So, you can see here again I have connected this point through the ground through resistor R and you can see that the same situation is there this fault current that is going to flow through this resistor, which is connected between neutral and earth.

And you can see I have shown again the vector diagram with Va, Vb and Vc 120 degree apart, again I have drawn the line voltages here and again I have shown the Ica which leads this Vca by 90 degree and Icb that leads the Vcb by 90 degree and by combining these two currents, you will have the current that is 3Ic and you can see that IF that is equal to 3Ic as we have shown this value. So you can see here that in this 3Ic that is exactly equal to your IF reactive. So that you can easily compensate.

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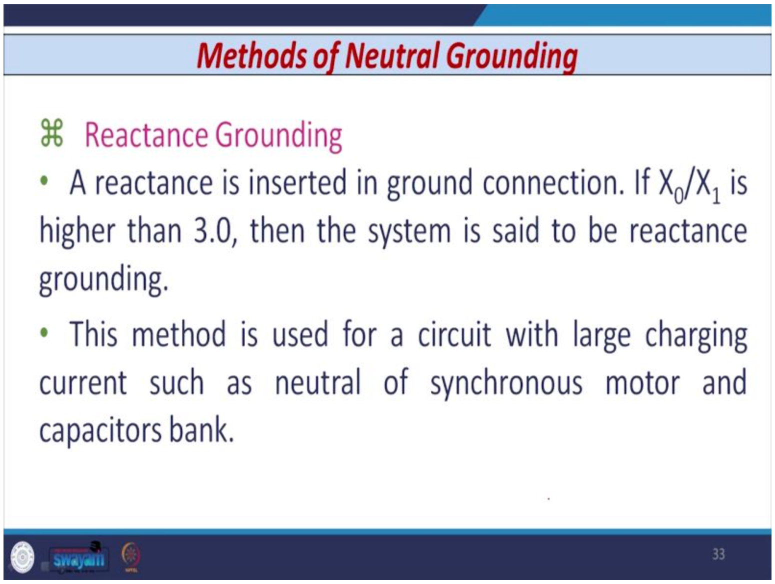

Methods of Neutral Grounding

⌘ Reactance Grounding

- A reactance is inserted in ground connection. If X_0/X_1 is higher than 3.0, then the system is said to be reactance grounding.
- This method is used for a circuit with large charging current such as neutral of synchronous motor and capacitors bank.

Now, the next type of grounding that is known as reactance grounding. So in case of reactance rounding, a reactance is inserted between the neutral and the earth. Whenever you use such type of grounding, the X0 by X1 of this type of reactor that is greater than 3, then and then the system is said to be reactance grounding. This type of method is used in a circuit when the large charging current such as the neutral of the synchronous motor and capacitor bank that is to be there. So this type of grounding is used in synchronous motor and capacitor bank.

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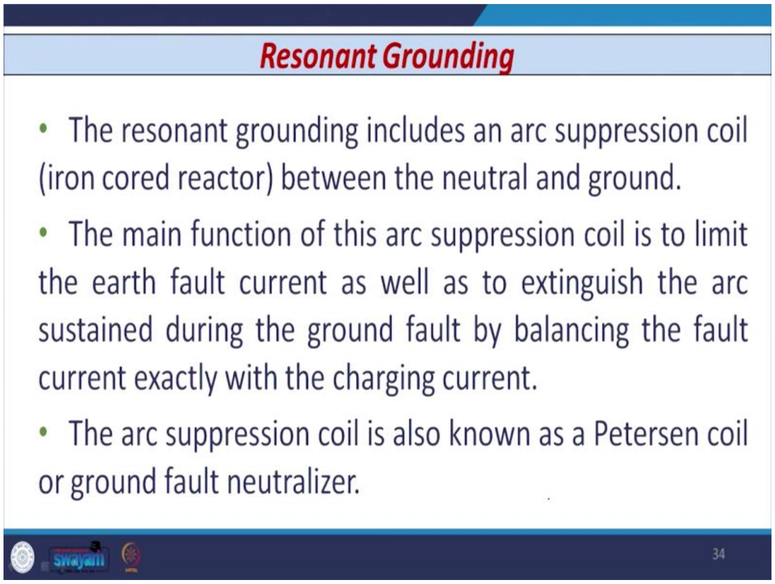

Resonant Grounding

- The resonant grounding includes an arc suppression coil (iron cored reactor) between the neutral and ground.
- The main function of this arc suppression coil is to limit the earth fault current as well as to extinguish the arc sustained during the ground fault by balancing the fault current exactly with the charging current.
- The arc suppression coil is also known as a Petersen coil or ground fault neutralizer.

Now next point that is known as the resonant grounding. Now, the resonant grounding includes the arc suppression coil. So it is basically arc suppression coil is nothing but the iron core reactor and that is connected between the neutral and the earth or the ground. The main function of this type of arc suppression coil is to limit the earth fault current as well as to extinguish the arc that is sustained during the ground fault by balancing the fault current which is exactly equal to the charging current that is IF is equal to 3Ic. The arc suppression coil is also known Peterson coil or the ground fault neutralizer.

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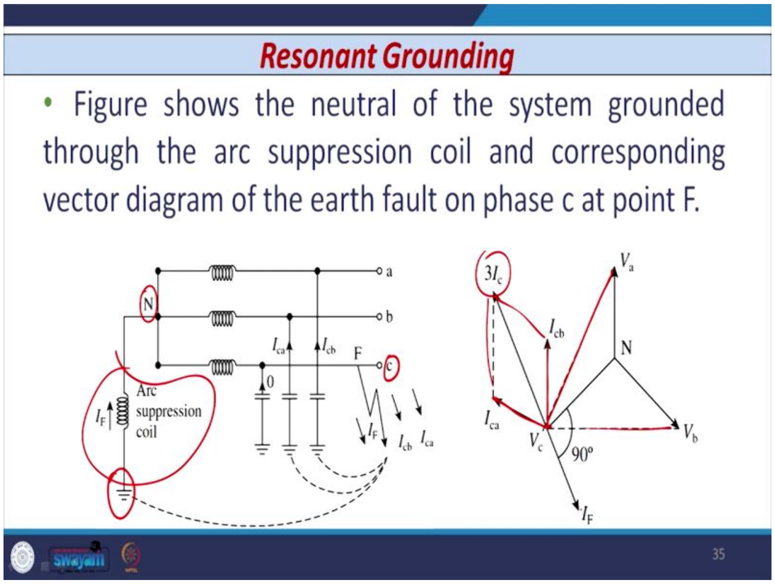

Resonant Grounding

- Figure shows the neutral of the system grounded through the arc suppression coil and corresponding vector diagram of the earth fault on phase c at point F.

So, if I consider the diagram of resonant grounding, then you can see that in this figure, the neutral of the system grounded through arc suppression coil that is here, so this neutral is connected through the earth through this coil and vector diagram is also shown again considering the same fault at point F in c phase. And again you can see that this current that leads this voltage by 90 degree and this current that leads this voltage by 90 degree and you will get this current by adding this two current, which is equal to exactly IF.

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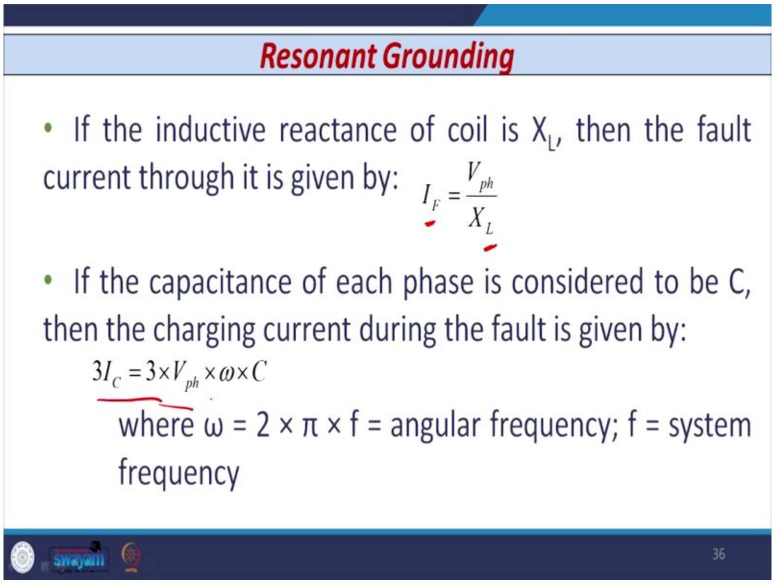

Resonant Grounding

- If the inductive reactance of coil is X_L, then the fault current through it is given by: $I_F = \frac{V_{ph}}{X_L}$
- If the capacitance of each phase is considered to be C, then the charging current during the fault is given by:

$$3I_C = 3 \times V_{ph} \times \omega \times C$$

where ω = 2 × π × f = angular frequency; f = system frequency

So, if the inductive reactance of say Peterson coil is let us say XL, then the fault current through it that is given by the IF which is equal to the phase voltage divided by the XL, that is the inductive reactance of the coil. If the capacitance of each phase that is considered to be, let us say, C, maybe in microfarad or millifarad, then the charging current during the fault that is given by 3Ic that is equal to 3 where Ic is equal to Vphase into omega into C, where omega is the angular frequency which is given by 2 pi f, where f is the system frequency.

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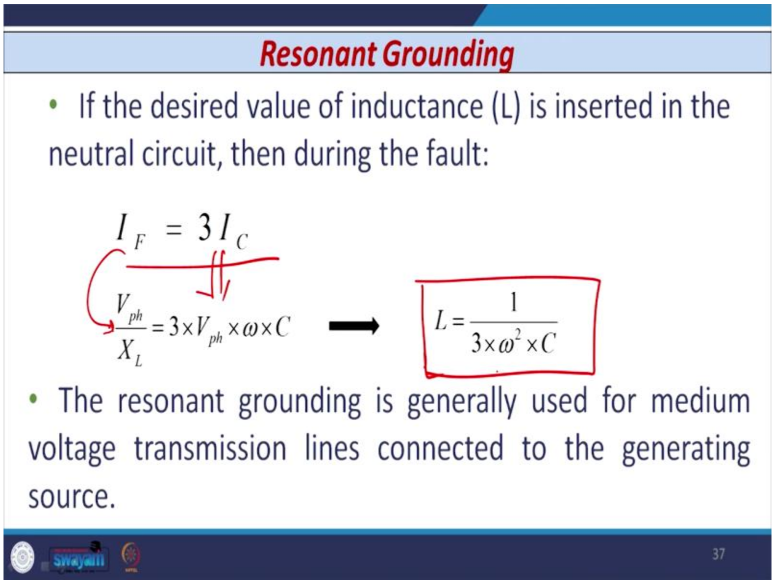

Resonant Grounding

- If the desired value of inductance (L) is inserted in the neutral circuit, then during the fault:

$$I_F = 3I_C$$

$$\frac{V_{ph}}{X_L} = 3\times V_{ph}\times\omega\times C \Rightarrow \boxed{L = \frac{1}{3\times\omega^2\times C}}$$

- The resonant grounding is generally used for medium voltage transmission lines connected to the generating source.

If the desired value of inductance L is inserted in the neutral circuit between neutral and earth, then during the fault IF is equal to 3Ic. So this IF that is equal to Vphase by XL and that is equal to 3Ic that is equal to 3 times Vphase into omega into C. So, using this you can easily find out the value of L that is to be inserted in the neutral circuit that is equal to 1 upon 3 omega square into C. So, the resonance grounding is generally used for medium voltage transmission lines connected to the generating source.

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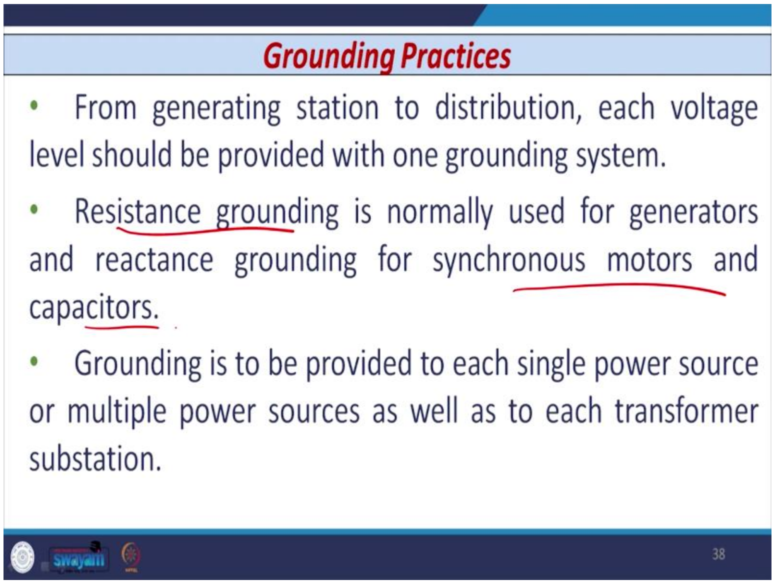

Grounding Practices

- From generating station to distribution, each voltage level should be provided with one grounding system.
- Resistance grounding is normally used for generators and reactance grounding for synchronous motors and capacitors.
- Grounding is to be provided to each single power source or multiple power sources as well as to each transformer substation.

So, let us summarize the different grounding practices used in from generation to the transmission to the distribution. So, resistance grounding that is normally used for generators, whereas the reactance grounding that is used for synchronous motors and capacitors or capacitor bank. The grounding that is to be provided to each single power source or the multiple power source as well as to each transformer in the substation also. So not a neutral of generator or transformer that is not the floated.

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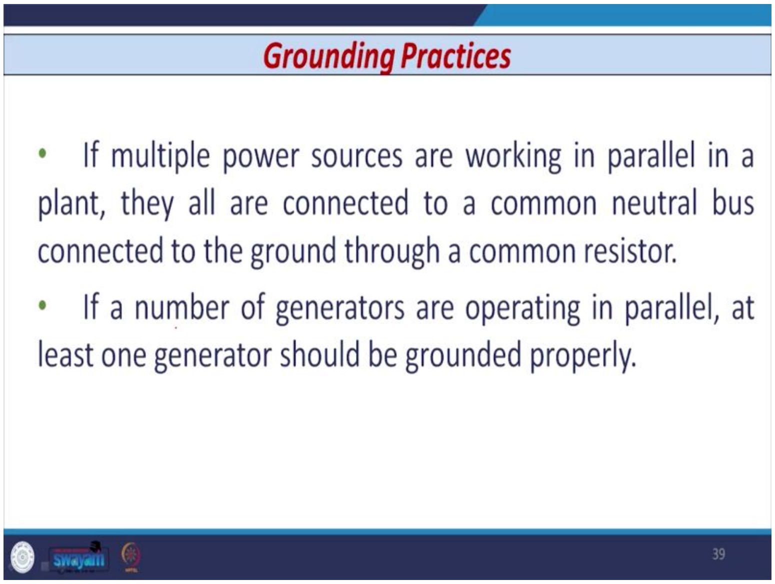

Grounding Practices

- If multiple power sources are working in parallel in a plant, they all are connected to a common neutral bus connected to the ground through a common resistor.
- If a number of generators are operating in parallel, at least one generator should be grounded properly.

If multiple power sources are working in parallel in a point, which is the case in case of large generating power stations where multiple generators are connected in parallel, then they all are connected at a common neutral bus connected to the ground through a common resistor. If a number of generators are operating in parallel, then at least one of the generator that should be grounded properly.

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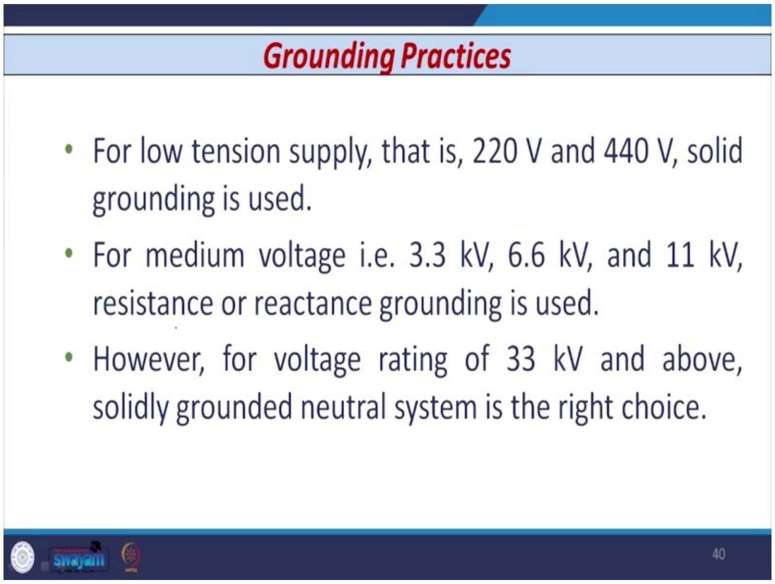

Grounding Practices

- For low tension supply, that is, 220 V and 440 V, solid grounding is used.
- For medium voltage i.e. 3.3 kV, 6.6 kV, and 11 kV, resistance or reactance grounding is used.
- However, for voltage rating of 33 kV and above, solidly grounded neutral system is the right choice.

For low tension supply maybe 220 or 440 volt, the solid grounding that is used whereas for medium voltage up to 3.3, 6.6 or 11 kV resistance or reactance grounding that can be used. However, at voltage rating of 33 kV and above, solidly grounded neutral system that is the best choice.

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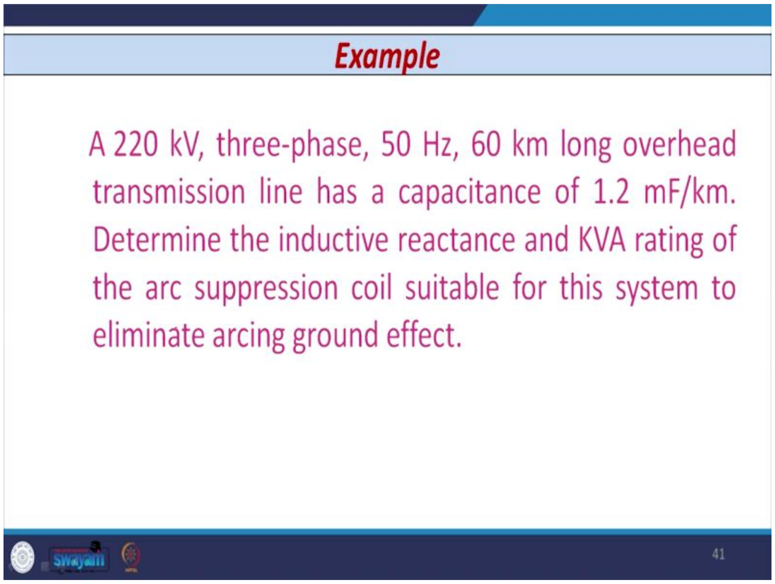

Example

A 220 kV, three-phase, 50 Hz, 60 km long overhead transmission line has a capacitance of 1.2 mF/km. Determine the inductive reactance and KVA rating of the arc suppression coil suitable for this system to eliminate arcing ground effect.

So, let us solve an example related to the Peterson coil. So, a 220 kV three phase 50 hertz 60 kilometer long overhead transmission line has a capacitance of 1.2 millfarad per kilometer. So you have to determine the inductive reactance and KVA rating of the arc suppression coil suitable for the system to eliminate the arcing ground effect.

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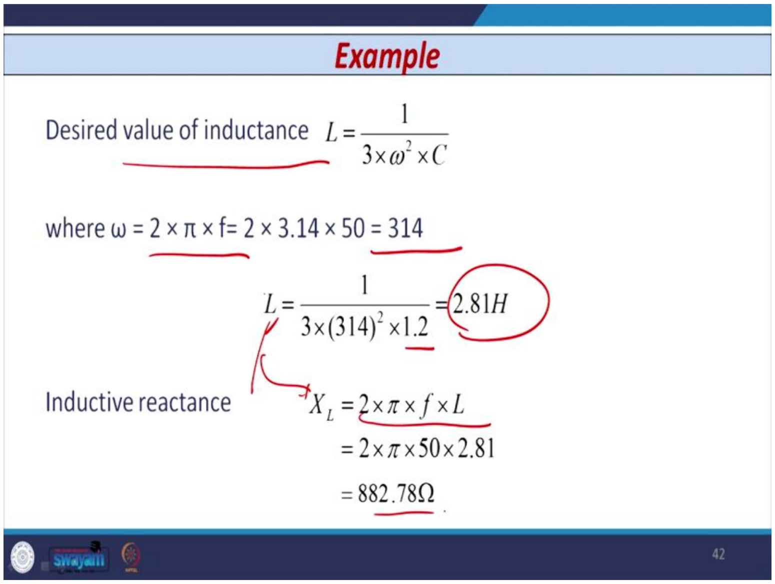

Example

Desired value of inductance $L = \frac{1}{3\times\omega^2\times C}$

where ω = 2 × π × f= 2 × 3.14 × 50 = 314

$$L = \frac{1}{3\times(314)^2\times 1.2} = \boxed{2.81H}$$

Inductive reactance

$$\begin{aligned} X_L &= \underline{2\times\pi\times f\times L} \\ &= 2\times\pi\times 50\times 2.81 \\ &= \underline{882.78}\Omega \end{aligned}$$

So, with this data, we need to find out the value of L that is the inductance which is 1 upon 3 omega square into C, where omega that is equal to 2 pi f, so that is 314. So, you can easily find out the value of f that is 3 into 314 square into 1.2. So, you will get 2.81 henry. With this value of L, you can easily calculate the XL that is 2 pi f L. So you can calculate the value which is 882.78 oham.

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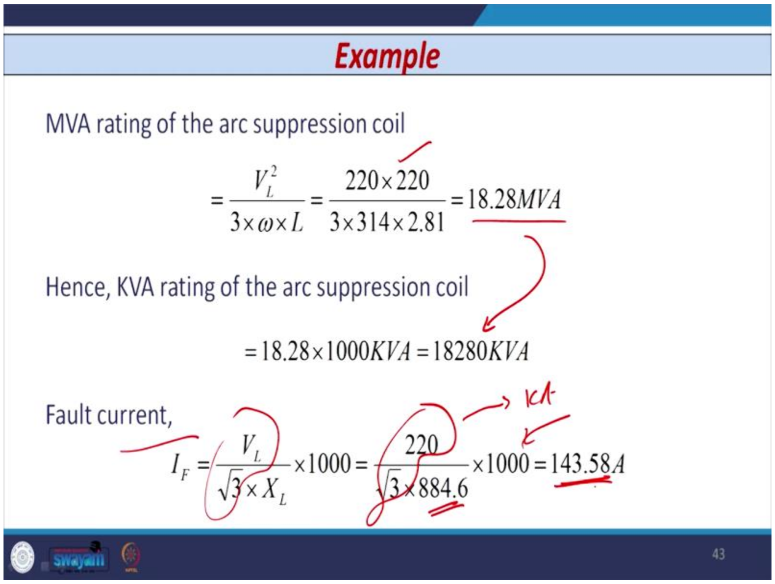

Example

MVA rating of the arc suppression coil

$$= \frac{V_L^2}{3\times\omega\times L} = \frac{220\times220}{3\times314\times2.81} = 18.28MVA$$

Hence, KVA rating of the arc suppression coil

$$= 18.28\times1000KVA = 18280KVA$$

Fault current,

$$I_F = \frac{V_L}{\sqrt{3}\times X_L}\times1000 = \frac{220}{\sqrt{3}\times884.6}\times1000 = 143.58A$$

kA

So the MVA rating of the arc suppression coil that is V square by 3 omega L. So you can easily find out V is given that is the voltage to 20 kV. So you can easily find out the value that is 18.28 MVA. If required, you can convert it into the KVA just by multiplying the 1,000. The fault current in this case that is the phase voltage that is VL by root 3, 220 kV by root 3 and the whole divided by XL, which you have already calculated. So, the fault current comes in kilo ampere and if you multiply by 1,000, then you will get the magnitude of current in ampere that is 143.58 ampere.

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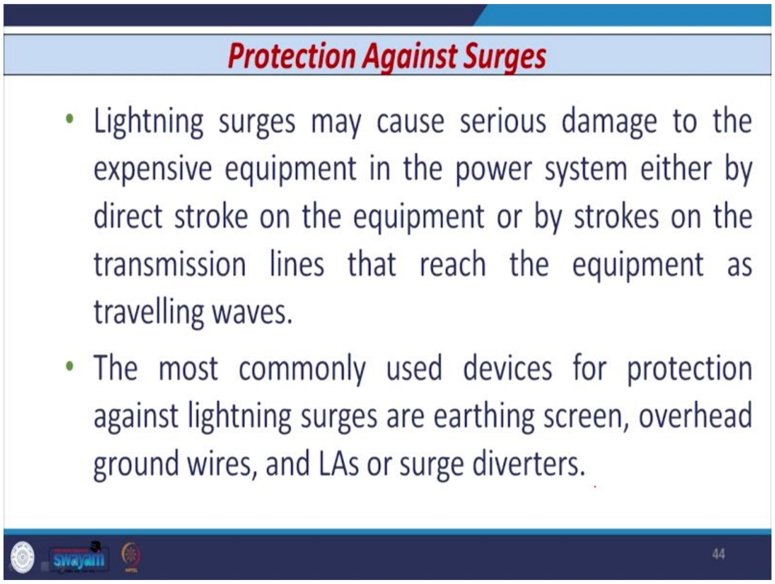

Protection Against Surges

- Lightning surges may cause serious damage to the expensive equipment in the power system either by direct stroke on the equipment or by strokes on the transmission lines that reach the equipment as travelling waves.
- The most commonly used devices for protection against lightning surges are earthing screen, overhead ground wires, and LAs or surge diverters.

Now, with this discussion, let us consider the protection against surges. So, we know that lightning surges may cause serious damage to the expensive equipment that is that we are using in the power system maybe either by direct stroke on the equipment or maybe by strokes on the transmission line that may reach to the equipment as a traveling waves. The most commonly used devices for protection against lightning surges are earthing screen, overhead ground wires, the surge diverters and the lightning arresters.

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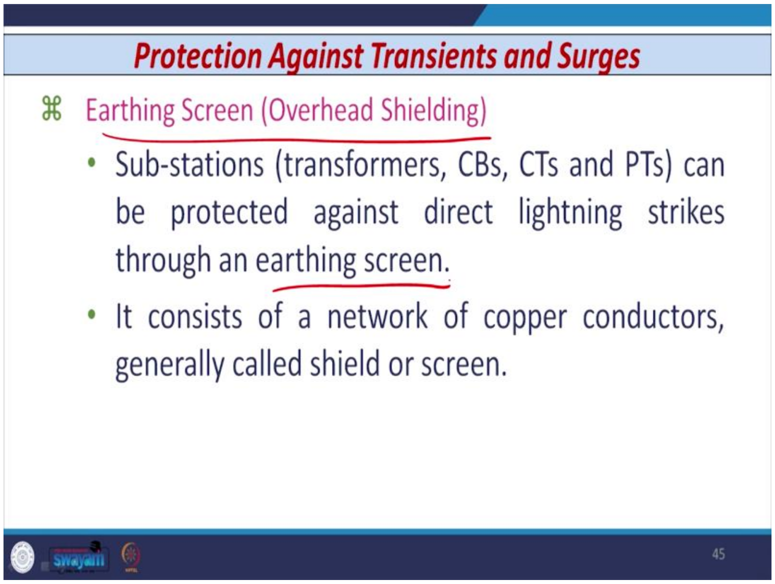

Protection Against Transients and Surges

⌘ Earthing Screen (Overhead Shielding)

- Sub-stations (transformers, CBs, CTs and PTs) can be protected against direct lightning strikes through an earthing screen.
- It consists of a network of copper conductors, generally called shield or screen.

So, let us discuss each and every equipment one by one. This equipment are used for protection against surges. So, first equipment that is known as the earthing screen, sometimes it is also known as overhead shielding. So sub-stations which includes transformers, circuit breakers, CTs, PTs that can be protected against direct lightening strokes through the earthing screen. So earthing screen consists of a network of copper conductors generally called the shield or the screen.

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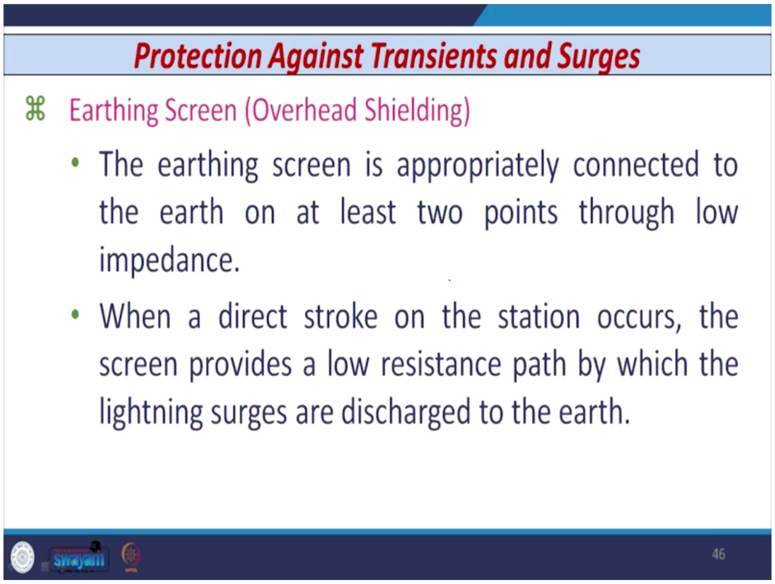

Protection Against Transients and Surges

⌘ Earthing Screen (Overhead Shielding)

- The earthing screen is appropriately connected to the earth on at least two points through low impedance.
- When a direct stroke on the station occurs, the screen provides a low resistance path by which the lightning surges are discharged to the earth.

The earthing screen is appropriately connected to the earth at least at two points through the low impedance. So whenever a direct stroke occurs on the station, the screen that is the earthing screen provides a low resistance path, by which the lightening surges that is discharged to the earth, and hence, this can be protected.

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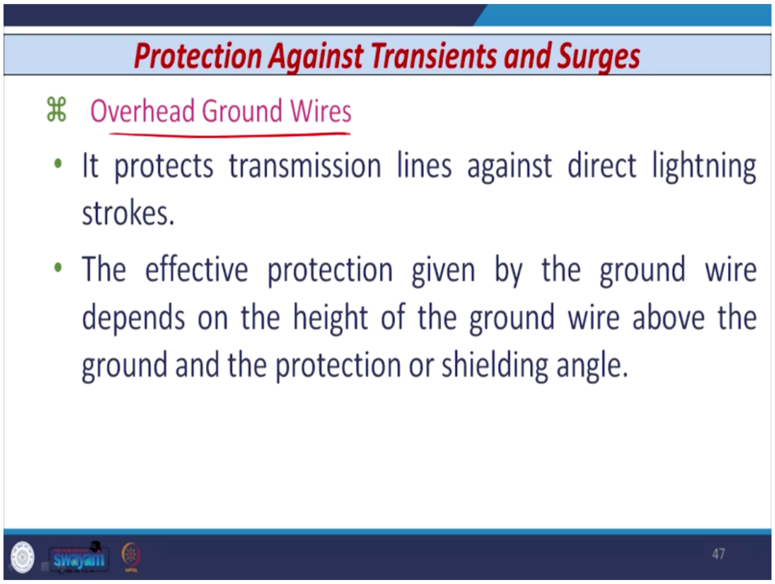

Protection Against Transients and Surges

⌘ Overhead Ground Wires

- It protects transmission lines against direct lightning strokes.
- The effective protection given by the ground wire depends on the height of the ground wire above the ground and the protection or shielding angle.

The second device that is known as overhead ground wires. So, overhead ground wires protect transmission lines against direct lightning strokes. The effective protection given by ground wire that depends on what is the height of the ground wire and what is the protection or shielding angle.

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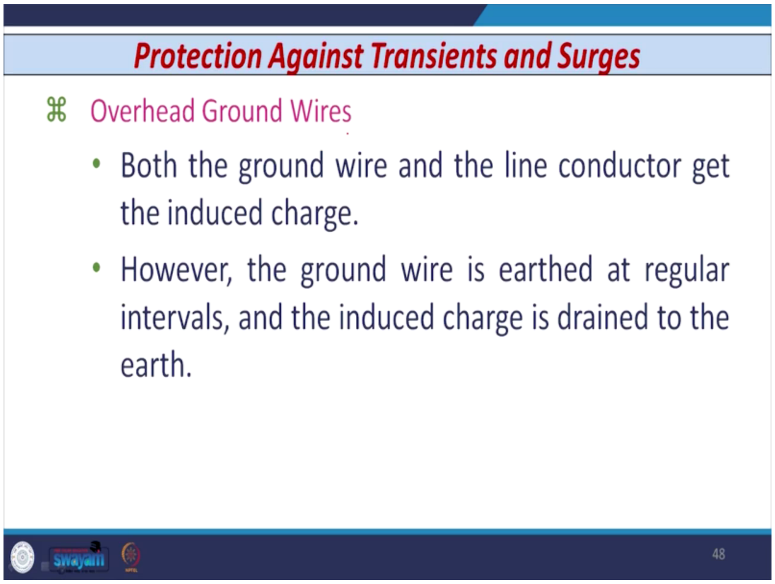

Protection Against Transients and Surges

⌘ Overhead Ground Wires

- Both the ground wire and the line conductor get the induced charge.
- However, the ground wire is earthed at regular intervals, and the induced charge is drained to the earth.

So, both the ground wire and the line conductor that get the induced charge, however, the ground wire is regularly earthed so induced charge that is drained or discharged to the earth.

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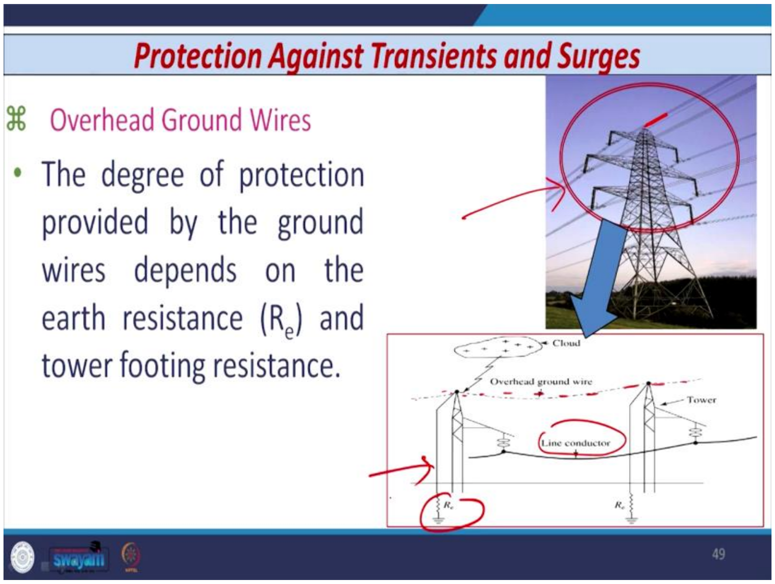

Protection Against Transients and Surges

⌘ Overhead Ground Wires

- The degree of protection provided by the ground wires depends on the earth resistance (R_e) and tower footing resistance.

So you can see here, there is a transmission tower and top of the tower we have the ground wire. So you can see here the, this is the ground wire shown here on the tower and below that there is a line conductor with insulator and that. So, you can see here that the degree of protection provided by the ground wire that depends on the value of this Re resistance, earth resistance and the tower footing resistance, this tower footing resistance.

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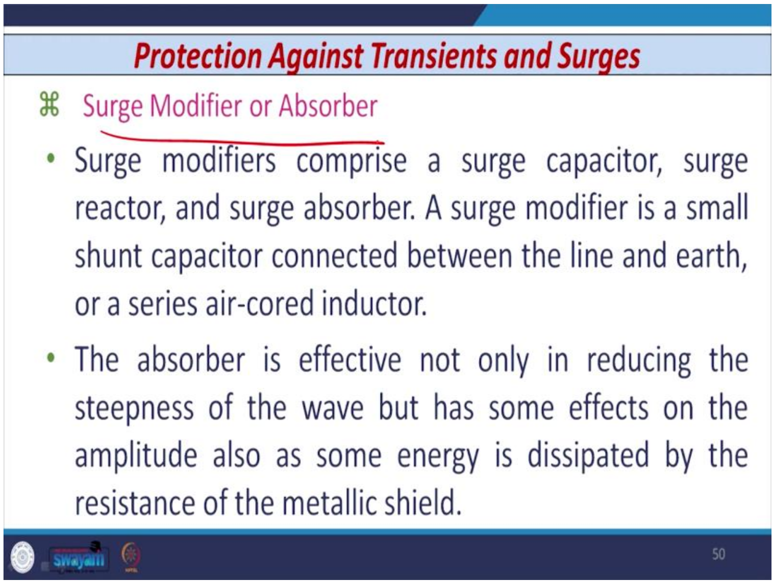

Protection Against Transients and Surges

⌘ Surge Modifier or Absorber

- Surge modifiers comprise a surge capacitor, surge reactor, and surge absorber. A surge modifier is a small shunt capacitor connected between the line and earth, or a series air-cored inductor.
- The absorber is effective not only in reducing the steepness of the wave but has some effects on the amplitude also as some energy is dissipated by the resistance of the metallic shield.

The third device used that is known as surge modifier or surge absorber. So, the surge modifiers comprises of surge capacitor, surge reactor and the surge absorber. The surge modifier is a small shunt capacitor connected between the line and earth and a series air-cored inductor. The surge absorber is effective not only in reducing the steepness of the wave, but it also reduces the effect of amplitude as the energy is dissipated by the resistance of the metallic shield.

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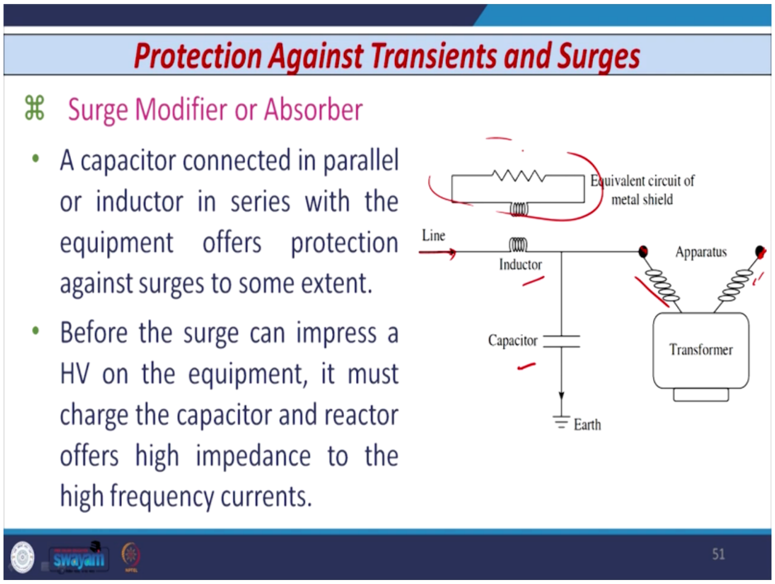

Protection Against Transients and Surges

⌘ Surge Modifier or Absorber

- A capacitor connected in parallel or inductor in series with the equipment offers protection against surges to some extent.
- Before the surge can impress a HV on the equipment, it must charge the capacitor and reactor offers high impedance to the high frequency currents.

So, if I consider the surge modifier or absorber, then you can see that this is the terminal of the apparatus, let us say, transformer. So, it has these two points and between this point and there is a line here, so you can connect the inductor that contains the inductor capacitor which is earth and this is the equivalent circuit of the metal shield.

So you can say that a capacitor is connected in parallel or inductor in series with the equipment. So this inductor and this capacitor both are connected and this is going to offer the protection against surges to some extent but not to the complete, it does not provide the complete protection. Before the surge can impress on a high voltage equipment, it must charge the capacitor and reactors offer high impedance to the high frequency current.

So, in this class, of course, the another last fourth equipment that is lightning arresters that is remaining, but that I will consider in the next class. So, in this class, I started discussion with the, what are the different sources which are responsible for generation of transient and surges, and then we also discuss the concept of neutral grounding. And then we started discussion with the, how the protection against surges or transient that is provided that is we started with the shielding screen and then the surge modifier and lightning arrester and so on, ground wire, of course. So concept of lightning arrester that we will discuss in the next class. Thank you.