

Power System Engineering
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Lecture – 19
Transient over voltages and Insulation coordination (Contd.)

So, we will come to you know another example that is your example 7.

(Refer Slide Time: 00:22)

(3) open end of a long energized line (Ferranti effect)
(4) ferroresonance

✓ EXAMPLE-7

An overhead line is connected in series with a cable. The overhead line has an inductance of 2 mH/km and capacitance of $0.01\ \mu\text{F/km}$. The cable has an inductance of 0.25 mH/km and capacitance of $0.102\ \mu\text{F/km}$. If a surge having a maximum value of 100 KV travels along the overhead line towards its junction with the cable, calculate

(a) the surge impedance of the line and cable.

So, it is given that an overhead line is connected in series with the cable, the overhead line has an inductance of 2 millihenry per kilometer, and capacitance of 0.01 micro farad per kilometer. The cable has an inductance of 0.25 millihenry the per kilometer and capacitance of 0.102 micro farad per kilometer.

Now if a surge having a maximum value of 100 KV, travels along the overhead line towards its junction with the cable calculate, the surge impedance of the line and cable just hold on then.

(Refer Slide Time: 01:14)

(b) the velocities of wave propagation in the line and cable. (2)

(c) the reflected and transmitted waves of voltage and current at the junction.

If the 100 kV surge originates in the cable, calculate the reflected and transmitted waves of voltage and current at the junction.

Soln

Surge impedance of overhead line

$$\rightarrow Z_1 = \sqrt{\frac{L_1}{C_1}} = \left(\frac{2 \times 10^{-3}}{0.01 \times 10^{-6}} \right)^{1/2} = \underline{447.2 \Omega}$$

Surge impedance of the cable Z_2

$$\rightarrow Z_2 = \sqrt{\frac{L_2}{C_2}} = \left(\frac{0.25 \times 10^{-3}}{0.102 \times 10^{-6}} \right)^{1/2} = \underline{49.5 \Omega}$$

Then you find the velocities of wave propagation in the line and cable, and C the reflected and transmitted waves of voltage and current at the junction right, if the 100 KV surge originates in the cable, calculate the reflected and transmitted waves of voltage and current at the junction.

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(c) the reflected and transmitted waves of voltage and current at the junction.

If the 100 kV surge originates in the cable, calculate the reflected and transmitted waves of voltage and current at the junction.

Soln

Surge impedance of overhead line

$$\rightarrow Z_1 = \sqrt{\frac{L_1}{C_1}} = \left(\frac{2 \times 10^{-3}}{0.01 \times 10^{-6}} \right)^{1/2} = \underline{447.2 \Omega}$$

Surge impedance of the cable Z_2

$$\rightarrow Z_2 = \sqrt{\frac{L_2}{C_2}} = \left(\frac{0.25 \times 10^{-3}}{0.102 \times 10^{-6}} \right)^{1/2} = \underline{49.5 \Omega}$$

So, solution how will do this first you have to compute the surge impedance of overhead line you know, first say overhead line said is Z_1 . So, Z_1 is equal to root over L_1 upon C_1 . L_1 is given to millihenry. So, it is 2 into 10 to power minus 3, and C_1 is given 0.01

micro farad so it is 0.01 into 10 to power minus 6 to the power root over. So, to the power half, if you calculate it will be 447 ohm.

Similarly, surge impedance of the cable Z_2 is equal to root over L_2 upon C_2 and L_2 is 0.25 into 10 to the power minus 3, because it is 0.25 millihenry. And C_2 is 0.102 micro farad so, 0.102 into minus 6 to the power half in square root. So, it is 49.5 ohm. So, surge impedance first you have to compute surge impedance of the cable, as well as surge impedance of the overhead line.

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Velocity of the wave in the overhead line

$$\gamma_1 = \frac{1}{\sqrt{L_1 C_1}} = \frac{1}{(2 \times 10^{-3} \times 0.01 \times 10^{-6})^{1/2}} = 2.24 \times 10^5 \text{ km/sec}$$

Velocity of the wave in cable,

$$\gamma_2 = \frac{1}{\sqrt{L_2 C_2}} = \frac{1}{(0.25 \times 10^{-3} \times 0.102 \times 10^{-6})^{1/2}} = 1.98 \times 10^5 \text{ km/sec}$$

Waves Originating in Overhead Line

When the waves originate in the overhead line and travel towards the cable, we will take,

$$Z_1 = 447 \Omega \quad \text{and} \quad Z_2 = 49.5 \Omega$$

Incident Values

Incident voltage in the overhead line $V_i = 100 \text{ kV}$

Next is that velocity of the wave in the overhead line, you know that say it is your this γ_1 we know, that 1 upon root over $L_1 C_1$. So, it is 1 upon L_1 and $C_1 L_1$ millihenry so, 10 to the power minus 3 into 0.01 into microfarad so, into 10 to the minus 6 to the power half. So, it is coming 2.24 into 10 to power 5 kilometer per second.

Similarly, velocity of the wave in the cable to it is given as 1 upon root over $L_2 C_2$ is equal to 1 upon 0.25 into 10 to power minus 3 into 0.102 into 10 to the power minus 6, because this is 0.25 million d. So, multiplied by 10 to the power minus 3 and this is a micro farad. So, multiple over 10 to the power minus it were half, it is coming 1.98 into 10 to the power 5 kilo meter per second.

After making all this, now waves originating in overhead line first, when the waves originating the overhead line and travels towards the cable we will have Z_1 is equal to

447 ohm and Z 2 is equal to 49.5 ohm right. Now it is given the incident voltage in the overhead line it is given 100 KV, this data is given that it is maximum value of 100 KV travels right. So, incident voltage of the overhead line that is v f is equal to 100 kilo volt.

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Incident current in the overhead line

$$i_f = \frac{V_f}{Z_1} = \frac{100 \times 1000}{447} = 223.7 \text{ Amp}$$

Transmitted Values

Line-to-cable transmission factor (refraction coefficient) for voltage,

$$\tau_{V1} = \frac{2Z_2}{(Z_1 + Z_2)} = \frac{2 \times 49.5}{(447 + 49.5)} = 0.1994$$

Transmitted voltage in the cable

$$v = \tau_{V1} \cdot V_f = 0.1994 \times 100 = 19.94 \text{ KV}$$

Line-to-cable transmission factor for current

$$\tau_{i1} = \frac{2Z_1}{(Z_1 + Z_2)} = \frac{2 \times 447}{(447 + 49.5)} = 1.80$$

Now, therefore, incident current, in the overhead line if is equal to V f upon Z 1 this all relationship we know. So, it is 100 KV. So, make it bold 100 1000 by 447 ohm that is 223.7 ampere.

Now, transmitted value now line to cable transmission factor that is refraction coefficient for voltage, we know that tau V 1 that it will it is actually 2 Z 2 upon Z 1 plus Z 2 this we have seen earlier. So, Z 2 is for that impedance of the cable. So, 2 into 49.5 divided by 447 that is that Z 1 and surge impedance of the overhead line, and Z 2 is the surge impedance of the cable so, 49.5 that is actually tau V here also coming 0.1994.

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$$i_f = \frac{V_f}{Z_2} = \frac{100 \times 1000}{447} = \underline{223.7 \text{ Amp}}$$

Transmitted Values

Line-to-cable transmission factor (refraction coefficient) for Voltage,

$$\gamma_{v1} = \frac{2Z_2}{(Z_1 + Z_2)} = \frac{2 \times 49.5}{(447 + 49.5)} = \underline{0.1994}$$

Transmitted voltage in the cable

$$v = \gamma_{v1} \cdot V_f = 0.1994 \times 100 = \underline{19.9 \text{ KV}}$$

Line-to-cable transmission factor for current

$$\gamma_{i1} = \frac{2Z_1}{(Z_1 + Z_2)} = \frac{2 \times 447}{(447 + 49.5)} = \underline{1.8006}$$

Similarly, transmitted voltage in the cable therefore, v is equal to it will be τV_1 into V_f . So, this τV_1 is 0.1994 and V_f is equal to 100 KV. So, it is 19.4 KV. So, line to cable transmission factor for current τ_{i1} we are making it is line to cable transmission factor for current only it will be τ_{i1} will be $2 Z_1$, that is your upon Z_1 plus Z_2 that is 2 into 447 divided by 447 plus 49.5 that comes 1.8006.

Actually earlier we have seen the τ for your reflection factor for the reflection refraction coefficient for the voltage and for the current is it is 2, basically τ_{v1} plus τ_{i1} if it is equal 2. So, if you add these two, 1.8006 and 0.1994 it will become 2. So, once you calculate this there is no need to calculate this 1 directly you can find out i_1 is equal to 2 minus V_1 that will give you the same value, but for your understanding I have just make it $i_1 \tau_{i1}$ is equal to $2 Z_1$ upon Z_1 plus Z_2 hence, it is 1.8006, but earlier we have proved the τ_{v1} plus τ_{i1} it is actually 2. So, find out 1 another 1 to get that subtract from 2. So, that is 1.8006.

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Transmitted current in the cable,
→ $i = \Gamma_{i2} \cdot i_f = 1.8006 \times 223.7 = \underline{402.8 \text{ Amp}}$
Alternatively, $i = \frac{v_2}{Z_2} = \frac{19.94 \times 1000}{49.5} = \underline{402.8 \text{ Amp}}$

Reflected Values
Reflection factor for Voltage,
→ $f_{v2} = \frac{(Z_2 - Z_1)}{(Z_1 + Z_2)} = \frac{(49.5 - 447)}{(447 + 49.5)} = \underline{-0.8006}$
Voltage reflected the overhead line
→ $v_b = f_{v1} \cdot v_f = -0.8006 \times 100 = \underline{-80.06 \text{ kV}}$
Reflection factor for current
→ $f_{i1} = \frac{(Z_1 - Z_2)}{(Z_1 + Z_2)} = -f_{v2} = \underline{0.8006}$

Therefore, transmitted current in the cable i is equal to Γ_{i1} into, if that is Γ_{i1} is 1.8006 into 223.7 right, because if it is equal to we have computed 223.7 ampere. So, it is actually 402.8 ampere.

So alternatively, what you can do is look for checking other way you can do, it i is equal to v upon Z_2 , Z_2 is the surge impedance of the cable and refracted voltage is actually we got 19.9 for KV just we have got it. So, make it in volt divided by forty 49.5 you will get 402.8 ampere same, this is the alternate calculation.

The way you want you can do it. So, alternative v upon Z_2 , but v is the you are your refracted that your what to call this refracted voltage this one, the transmitted voltage right, or refracted voltage whatever you call that is 19.4 KV. So, it means same thing you will get this is and the same thing, you will get either this way you can compute or directly you can compute this way.

Now, reflected values now reflection factor for voltage, we know the formula for voltage it will be Z_2 minus Z_1 upon Z_1 plus Z_2 , this we have seen earlier. So, Z_2 is equal to 49.5 and Z_1 is equal to 447. So, 49.5 minus 447 divided by Z_1 plus Z_2 . So, 447 plus 49.5 that comes actually minus 0.8006 therefore, voltage reflected the overhead line that v_b is equal to Γ_{v1} into v_f . So, it is minus 0.8006 into 100 KV. So, minus 80.06 KV.

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Alternatively, $i = \frac{v}{Z_2} = \frac{19.94 \times 1000}{49.5} = \underline{402.8 \text{ Amp}}$

Reflected Values

Reflection factor for voltage,

$$\rightarrow f_{v1} = \frac{(Z_2 - Z_1)}{(Z_1 + Z_2)} = \frac{(49.5 - 447)}{(447 + 49.5)} = \underline{-0.8006}$$

Voltage reflected the overhead line

$$\rightarrow v_b = f_{v1} \cdot v_f = -0.8006 \times 100 = \underline{-80.06 \text{ kV}}$$

Reflection factor for current

$$\rightarrow f_{i1} = \frac{(Z_1 - Z_2)}{(Z_1 + Z_2)} = -f_{v1} = \underline{0.8006}$$

Now, reflection factor for the current, it will be just your what you call negative of this 1 negative; that means, it will be 0.8006 we have seen earlier. If it this is negative then for current it will be positive. So, it will be $Z_1 - Z_2$ upon $Z_1 + Z_2$ actually it is minus ρ_v it is equal to 0.8006.

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Current reflected back in the overhead line

$$i_b = \frac{-v_b}{Z_1} = \frac{-(-80.06)}{447} = 179.1 \text{ Amp}$$

Fig. 17 Voltage and current distributions

So once you get this, then that current reflected back, in the overhead line that i_v will be is equal to minus v_b upon Z_1 is equal to minus in bracket minus 80.06 upon 447, so 179.1 ampere.

So, now and the diagram voltage and current distribution it initially the traveling of 100 hundred KV, but voltage 80.6 is reflecting back right, this one, this one that is your minus 80.06 KV so ultimately resultant here, give will be your this is that your what you call that this is side overhead line this is cable, and this is the junction right. So, I made it like this. So, this is your 19.94 KV.

Similarly, for the current that 223.7 the deflected current was your this much or here, it is here it is 179.1 ampere. So, it is actually 223.7 plus this height is your 402.8 ampere. So, this is your current wave, and this is your voltage wave. So, volt this is actually I have marked as a figure 17. So, this is that current and voltage waveform right, it is a step function you have considered, once this transient over voltage is over. So, next we will come to your, what you call that insulation coordination.

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Insulation Coordination

(A) Basic Impulse Insulation Level (BIL)

Reference insulation levels - expressed in impulse crest (peak) voltage with a standard wave not longer than a 1.2 x 50-μs wave. It is determined by tests made using impulses of a 1.2 x 50-μs waveshape.

BIL is usually defined as a per unit of maximum value of the line-to-neutral voltage. For example, for 345 kV, it is

$$1 \text{ pu} = \sqrt{2} \left(\frac{345}{\sqrt{3}} \right) = \underline{282 \text{ kV}}$$

So that BIL of 2.7 pu = 760 kV.

So, first thing is that basic impulse insulation level in short we call bil. So, reference your insulation level express in impulse crest that is the peak voltage, with a standard wave not longer than 1.2 into 50 micro second this we have seen earlier right, that is crest value or peak value reaches in 1.2 micro second and 50 percent of that reaches in 50 micro second right. So, that is we call that is 1.2 into 50 micro second waves.

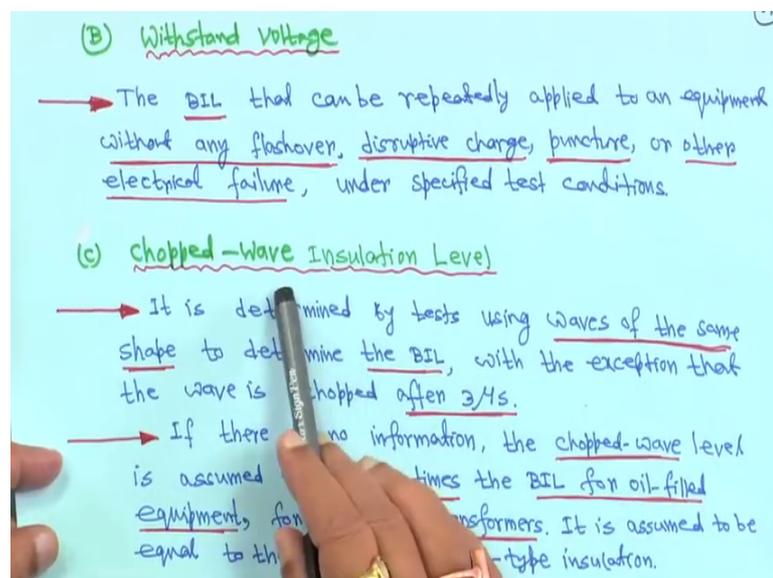
So; that means, insulation level expressive impulse crest peak or peak value, with standard wave not longer than this 1 i mean 1.2 into 50 micro second right wave, it is determined by test made using impulses of 1.2 into 50 micro second waves. Actually this

is very you know this is recommended, but in reality when you will try it may not be exactly this 1.2 and into 50, but around that around that value it will be there right.

So, particularly for transformer impulse test if you do so, you may not get that ideal value, but this is the standard you have to see around that only. So, BIL that is your basic impulse insulation well usually defined as a per unit of maximum value of the line to neutral voltage right that is for example, say for 340 KV line, suppose 340 KV say it is 1 pu is equal to first these 345 by root 3. So, line to neutral you made then multiplying by root 2; that means, the peak value. So, it will be 282 KV that is 1 p per unit for example, if it is a 345 KV, then 345 by root 3 is the line to neutral voltage that is phase voltage, and multiplied by root 2. So, it will be peak value that is 282 KV.

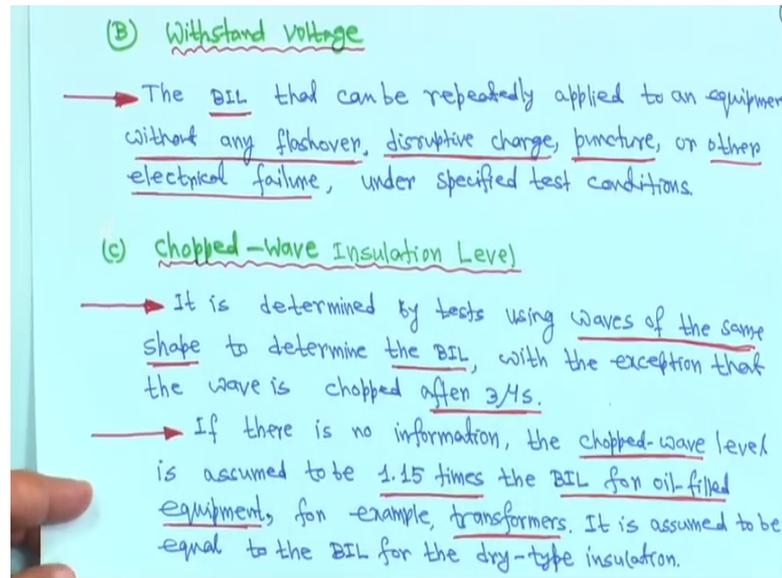
So, that supposes if you have BIL of 2.7 pu that means, 2.7 into 282 that will give you because 1 pu is equal to 282 KV. So, that will give you 760 KV right. So, this is your idea of basic your impulse insulation level.

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Now, next one is withstand voltage right that was the BIL that can be repeatedly applied to an equipment without any flashover, then disruptive charge puncher or other electrical failure under specified test condition. So, whenever they are testing the equipment they test all sort of things so, this is actually withstand voltage. Now, another thing is chopped wave insulation level right.

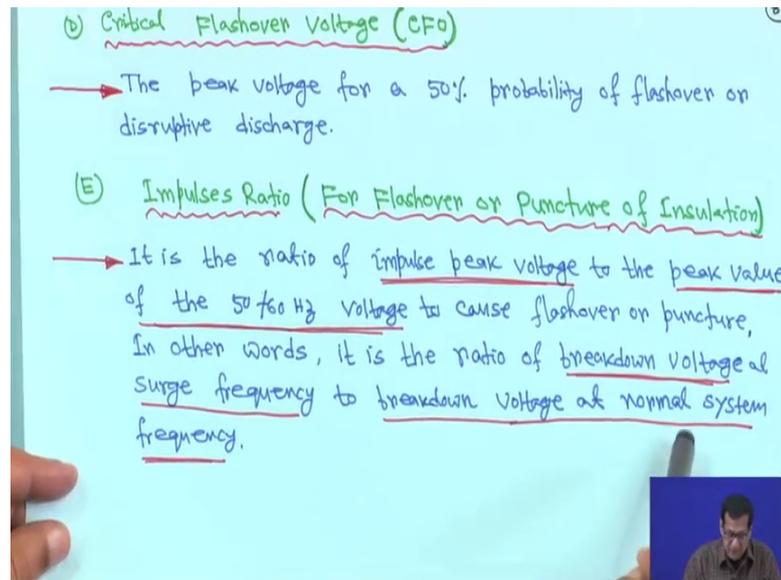
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In this gate is what happened it is determined by the test using waves of the same shape same shape means, that 1.2 into your that 50 microsecond that the wave shape to determine the BIL right. So, there is basic impulse insulation level so, with the exception that the way we chopped after 3 micro second; that means, it is applied, but after that it is chopped at 3 micro second. So, if there is no information the chopped wave level is assumed to be 1.15 times the bill for say oilfield equipment for example, transformer. So, it is assumed to be equal to the BIL for the dry type insulation.

So, some experimental setup they do and they take 1.15 times for the chopped wave right, if there is no information you get they will assume that is 1.15 times the BIL for oilfield equipment for example, transformer. So, now then critical flashover voltage they call CFO.

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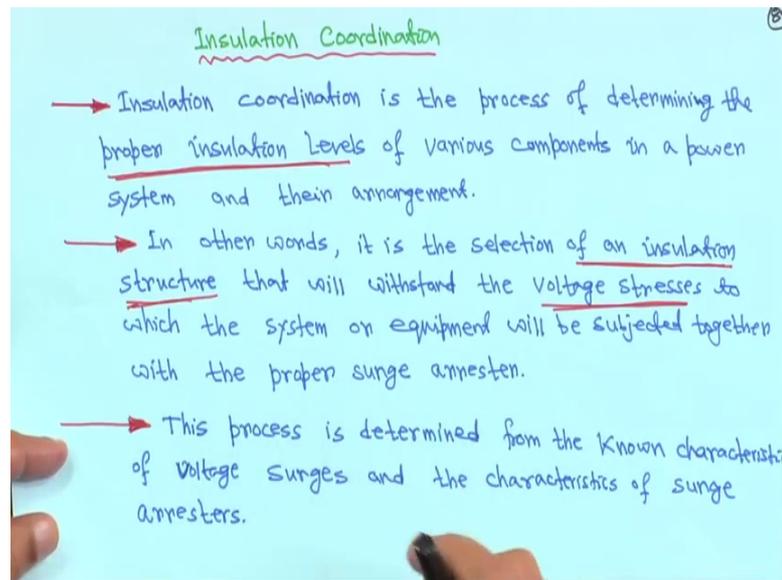


The peak voltage for a 50 percent probability of flashover or destructive discharge, this is called your critical flashover voltage.

Now, impulse ratio for flashover over or puncture of insulation, impulse issue it is the ratio of impulse peak voltage to the peak value, you look listen it is the ratio of the impulse peak voltage whatever you have to the peak value of the 50 to 6 either 50 hertz system or 60 hertz system. That is why I am making it 50 slash 60 hertz voltage to cause flashover or puncture right.

So, in other words it is the ratio of breakdown voltage a surge frequency to breakdown voltage at normal system frequency, because when you are considering that is the ratio of impulse peak voltage right base. So, basically it is a breakdown voltage at the surge frequency to the breakdown voltage at normal system frequency, this is that called impulse ratio. So, this is theory only not numericals, but you have to know all these things right.

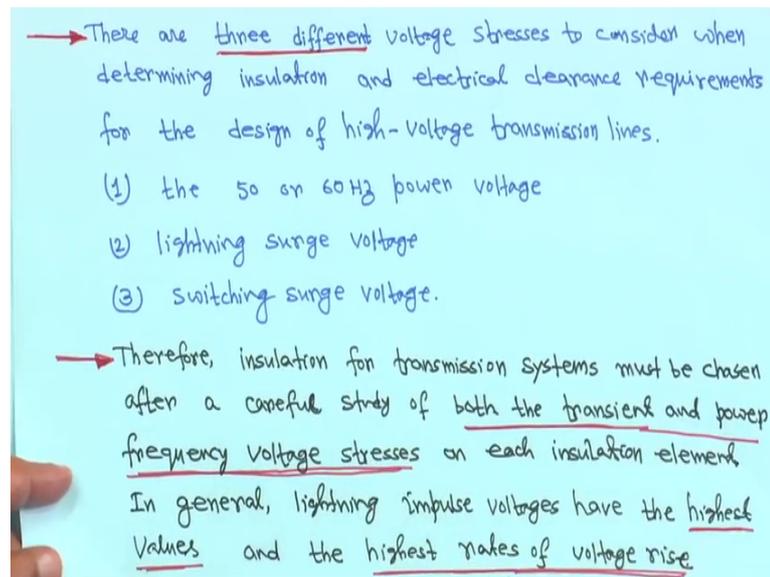
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Now, insulation next is insulation coordination this is quite important. So, insulation coordination is the process of determining the proper insulation level of various components in a power system, and their arrangement. So, in other words it is the selection of an insulation structure that will withstand the voltage stresses, which the system or equipment will be subjected together with the proper surge arrester, actually in this course lightning arrester will not cover, but you have the if you go to any power station or substation you will find lightning arrester is there.

So, that is why in other words it is the selection of an insulation structure that will withstand the voltage stresses is the system or equipment will be subjected together with the proper surge arrester; that means, particularly this maximum switch or impulse or surge comes due to the lightning stroke. So, that is why the lightning arrester is designed in such a person such that it can protect the equipment, and they when they design all sort of things they consider all the worst cases accordingly that surge arrester rating will be determined. Such that it can protect the you know equipment in the; its substation for example, say right this process is determined from the known characteristic of voltage surges and the characteristic of surge arresters.

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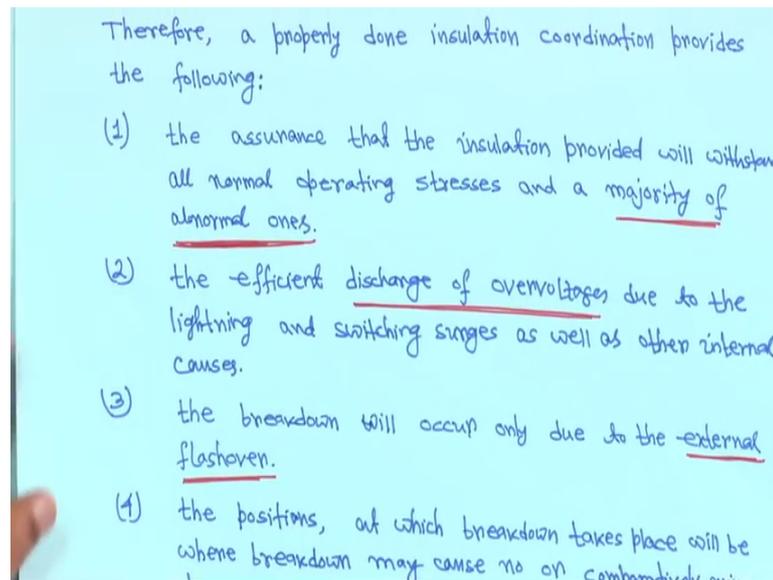


So, different type of your what you call lightning arrester so, that were that is beyond the scope for this course. Now there are 3 different voltage stresses to consider when determining the insulation and electrical clearances requirement fasting is for the design or high voltage transmission line, one is the 50 or 60 hertz power voltage, lightning surge voltage, and switching surge voltage, different type of switching is there in the literature also, but I have skipped those things then it will consume more time for this what whatever basic things are there, whatever actually we need to learn those things only we will see that.

So, lightning surge voltage and switching surge voltage, but these lightning surge voltages is a very severe 1. Therefore insulation for transmission system are with chosen after careful study of both the transient and power frequency voltage stresses on each insulation element. So, one has to what insulation is a you know, I mean it is a we power comes, but there are many technical things are there and this insulation you are not one of the main thing right. Particularly the protect from the fault from this type of lightning stroke or switching surges right. So, those kind of thing insulation plays a significant role.

So, in general lightning impulse voltage have the highest values, and the highest rate of voltage rise. So, lightning stroke is the severe 1 among all this.

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So, therefore a properly done insulation a coordination provides the following. The assurance that the insulation provided will withstand all normal operating stresses, and the majority of abnormal ones; that means, whatever insulation you make that it will withstand the normal operating stresses right. As well as a majority of abnormal ones I told you that it may be switching surges lightning surges or some fault. So, all are normal it will sustain.

Then the efficient discharge of over voltages due to the lightning and switching surge as well as other you are what you call internal causes. So, that also efficient discharge over voltages due to the lightning and switching surges as well as other internal causes. So, all these things insulation has to sustain, it has to withstand all sort of things number 3 is the breakdown will occur only due to the external flashover, there is a possibility of breakdown due to the external flashover.

And second thing is that the positions at which breakdown take place will your will be higher breakdown may cause no or no or comparatively minor damage, if there is a breakdown also the damage should be minor right, but occasionally it happens your what is called for example.

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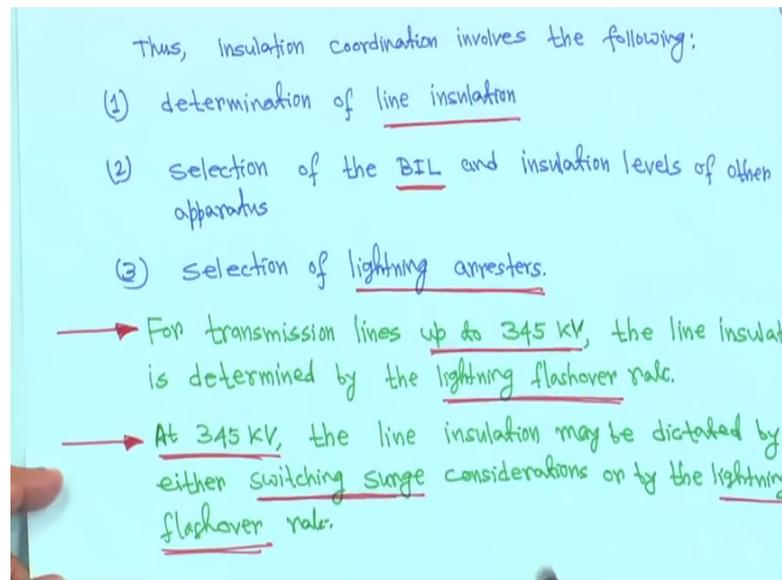
- (1) the assurance that the insulation provided will withstand all normal operating stresses and a majority of abnormal ones.
- (2) the efficient discharge of overvoltages due to the lightning and switching surges as well as other internal causes.
- (3) the breakdown will occur only due to the external flashover.
- (4) the positions, at which breakdown takes place will be where breakdown may cause no or comparatively minor damage.

When I was listening some lecture from renowned parson say, when it is a very interesting thing. Suppose when you are testing suppose you have tested say 200 same equipment says to say 200 numbers.

As soon as when you are testing you find that your testing is but after, suppose 200 the same equipment right and, but after the testing you do not know out of that 200 that 1 or 2 might have got damaged, but you do not know because when you are testing it was so, these are called hidden kind of fault in that equipment. So, there is a possibility of that thing also right.

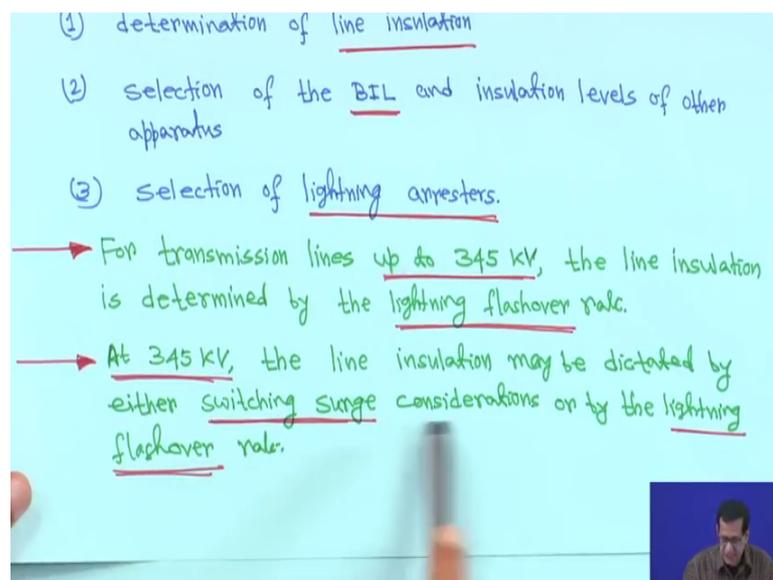
So, but anyway when we test at the time we found everything is a clear, but we do not know maybe out of several same equipment maybe 1 or 2 have become defective after the test that is not because, we are not testing after that directly we are going for your installing that right. So, these are called hidden fault what we will not discuss about those things.

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So, does the insulation coordination actually involves the following, first thing is the determination of line insulation selection of the BIL value, and insulation levels of other apparatus, and selection of lightning arresters this lightning arrester will not study in this course, but the selection of light we have to design that proper rating of the lightning arrester.

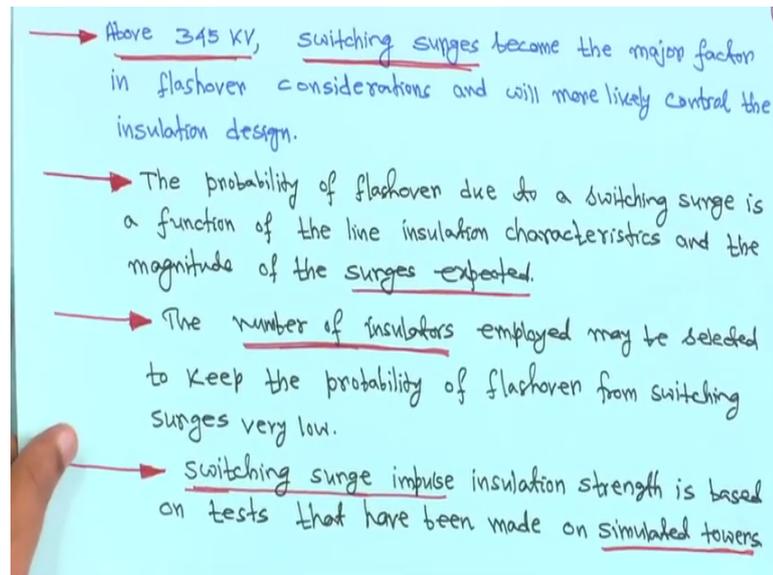
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So, for transmission lines say up to 345 the KV line insulation is determined by lightning flashover rate only, but if it is at 30, 345 KV the line insulation may be dictated by either

switching such consideration or by the lightning flashover rate. So, because voltage level is very high so, insulation level, whatever you see it will determine switching surge consideration or by the lightning flashover rate so, that actually the testing at that you know how long that insulation can sustain that you are what you call at that voltage level.

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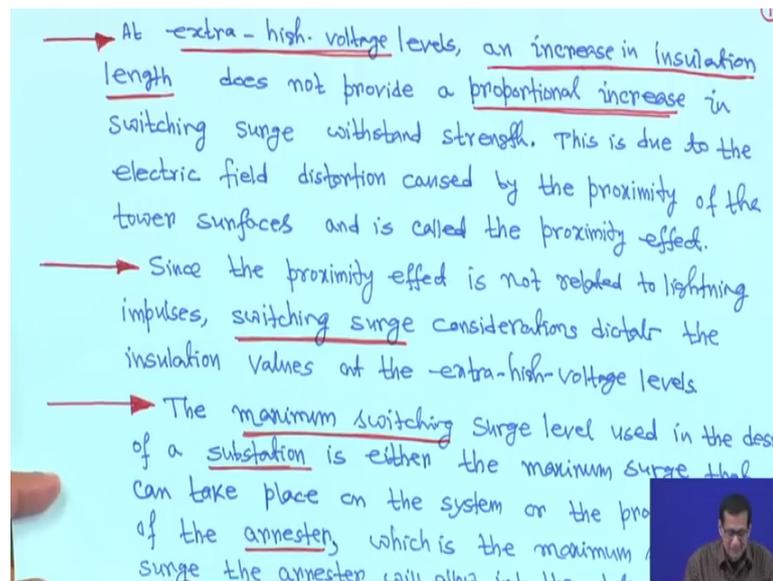
You I do not know whether you have seen that insulation of transformer winding or not, how they how they make the insulation for the transformer winding. If you have anything you can see 1 open transformer winding, and each winding how they insulated right, then you will be you will have some good ideas about insulation thing insulation plays a very significant role.

So, above 345 KV switching surges become the major factor of flashover, consideration and will more likely control the insulation design. So, if voltage level is above 345 KV say then of course, switching surges become the major factor in flashover consideration. So, now the probability of flashover due to a switching surge is a function of the line insulation characteristic and the magnitude of the surges expected right.

So, the number of insulators employed maybe selected to keep the probability of flashover from switching surges very low. So, all these factors actually you have to consider, now switching surge impulse insulation strength is based on tests that have been made on simulated towers.

So, all sort of tests you have to make it right switching surge impulse insulation strength is based on tests that have been made on simulated tower. So, all sort of before you put it in you know installation that you have to consider, that all sort of factors all sort of testing, just directly manufacturing and you are not putting it after that you have to test, it whether it can sustain or not all those high voltage stresses.

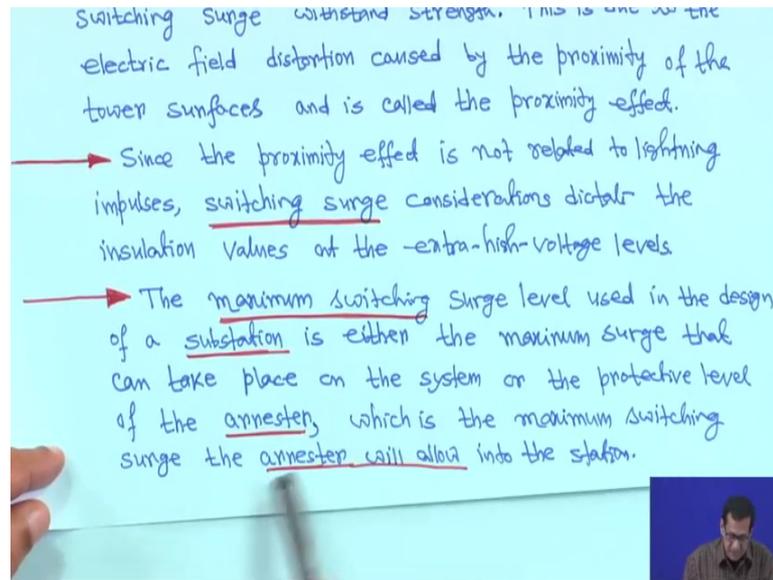
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Now, an extra high voltage levels, and increase in insulation lengths does not provide a proportional increase in switching surge which turns strength, then we just like increasing the insulation length does not mean, that proportionality increase the switching sustain.

This is due to the electric field distortion caused by the proximity of the tower surfaces, and is called a proximity effect since the proximity effect is not related to the lightning impulses. So, switching surge considerations dictate the insulation values at the extra high voltage levels. So, at the extra voltage level switching surge thing is the main concern for the insulation.

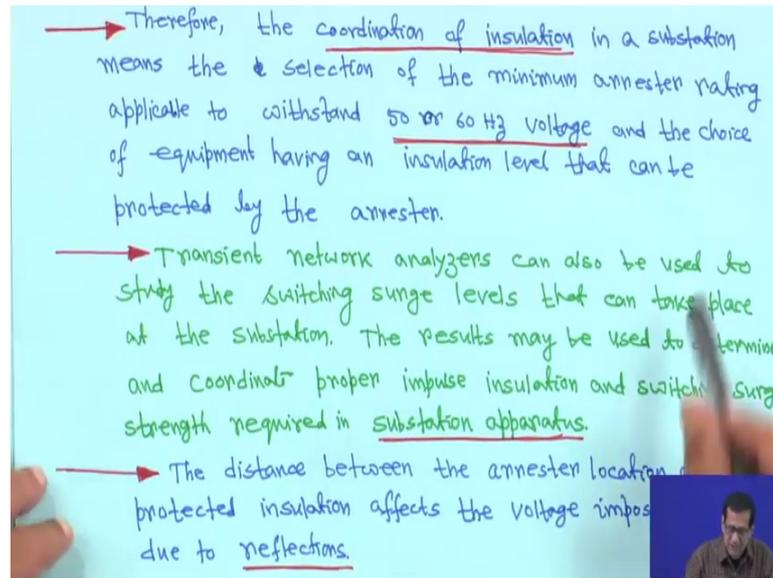
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The maximum switching surge level used in the design of a substation, is either the maximum surge that can take place on the system, or the protective level of the arrester that is lightning arrester which is the maximum switching surge the arrester will allow into the station. So, you have to design that lightning arrester in such a person that it can maximum switching surge that arrester, can allow some current rate, in you have to choose different type of arresters are there.

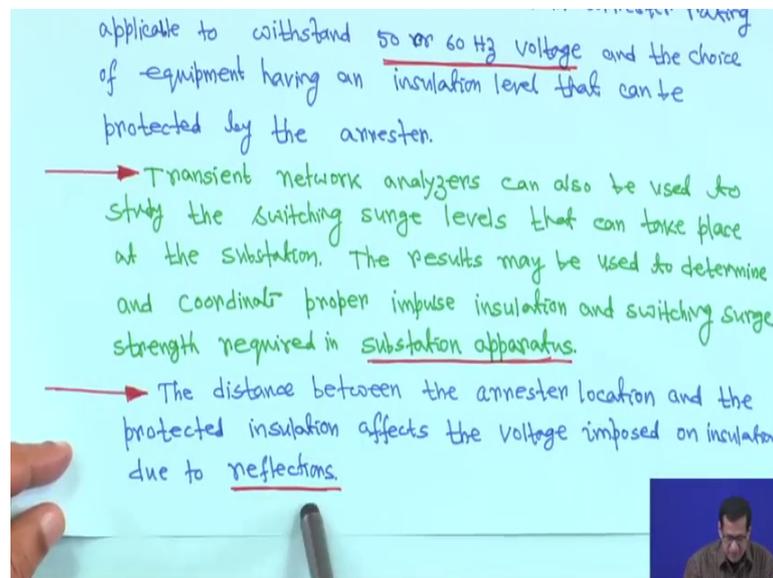
So, these are the significant thing. But I have seen in substation that lightning arrester also due to that heavy lightning stroke, I have seen that even arrests also so a lightning arrester also failed. This I have seen in the past, somewhere in the substation we found due to that due to that arrester failure some other equipment also got damaged. So, I has to be very careful for designing all sort of thing particularly to protect all the equipments, that is due to your lightning stroke switching surges etcetera.

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Therefore the coordination of insulation in a substation means the selection of the minimum arrester rating applicable to withstand 50 or 60 hertz voltage, and the choice of equipment have an insulation level that can be protected by the arrester.

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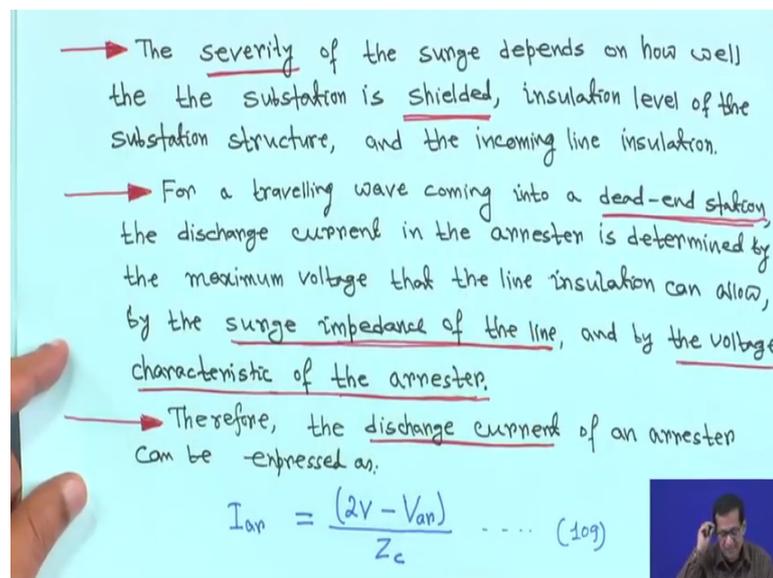
So, arrester design lightning arrester selection is main important in substation. So, transient network analyzer can also be used to your study the switching surge level that can take place at the substation. The result may be used to determine, the determine and

coordinate proper impulse insulation and switching surge strength requiring substation apparatus.

If you go to any substation you will find this lightning arresters are there, and you will say once you visit this apparently from the distance, it will go you go to go and see all these things like lightning arresters, then CT that is current transformer, then potential transformers how the current transformers are connected, then the insulators, then the transformer circuit breakers each and everything and one can learn.

So, distance between the arrester location and the protected insulation affect the voltage imposed on insulation due to reflections look so many things are there.

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→ The severity of the surge depends on how well the the substation is shielded, insulation level of the substation structure, and the incoming line insulation.

→ For a travelling wave coming into a dead-end station, the discharge current in the arrester is determined by the maximum voltage that the line insulation can allow, by the surge impedance of the line, and by the voltage characteristic of the arrester.

→ Therefore, the discharge current of an arrester can be expressed as:

$$I_{ar} = \frac{(2V - V_{an})}{Z_c} \dots (109)$$

So, the severity of the surge depends on how well the substation is shielded right; that means, you have to protect the substation insulation level of the substation structure, and the incoming line insulation. So, all these things onw has to consider, one is that insulation level of the substation structure and the incoming line insulation.

For a traveling wave coming into a dead end station that is coming at the substation end so, dead end station the discharge current in the arrester is determined by the maximum voltage that the line insulation can allow, allow you know it. So, whatever is the maximum voltage or stress that line institution can allow, based on that only arrester your

we are have to called a lightning arrester current is determined right, by the surge impedance of the line and by the voltage characteristic of the arrester.

So, therefore, the discharge current of an arrester just I am writing can be expressed as it is generally given as V_{is} equal to I_{ar} arrester, lightning surge is equal to $2V$ minus v_{ar} upon Z_c , that is v_{actual} is equal to magnitude of your incoming surge voltage, and v_{ar} is arrested terminal voltage.

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Where,

- I_{ar} = arrester current
- V = magnitude of incoming surge voltage
- V_{ar} = arrester terminal voltage
- Z_c = surge impedance of line.

→ Fig.17 shows the insulation coordination between an oil-filled equipment (e.g., transformer) and a surge arrester. The arrester impulse sparkover voltage is compared to the chopped-wave test level of the transformer. A more meaningful comparison is the arrester sparkover with the wave from

So, this way therefore, this your I_{ar} is the arrester current v is the magnitude of incoming surge voltage v_{ar} is arrested terminal voltage, and Z_c is a surge impedance of the line.

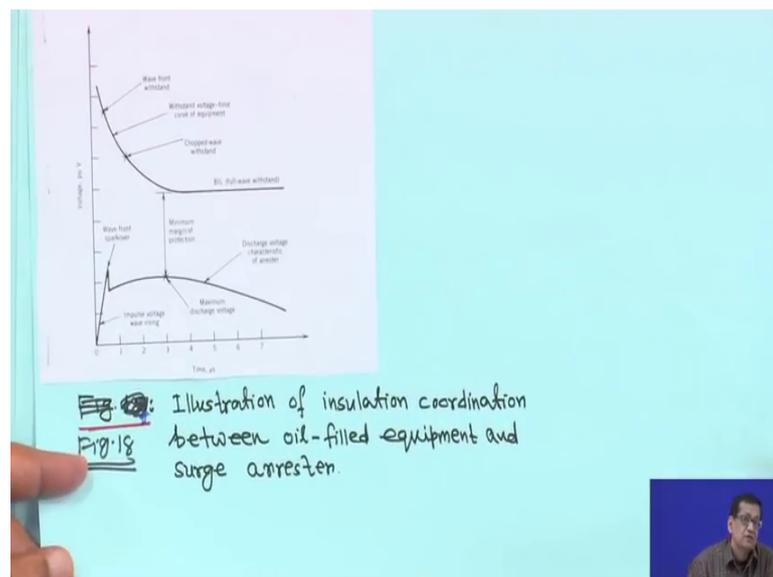
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I_{an} = arrester current
 V = magnitude of incoming surge voltage
 V_{ar} = arrester terminal voltage
 Z_c = surge impedance of line.

→ Fig.17 shows the insulation coordination between an oil-filled equipment (e.g., transformer) and a surge arrester. The arrester impulse sparkover voltage is compared to the chopped-wave test level of the transformer. A more meaningful comparison is to compare the arrester sparkover with the wave front test.

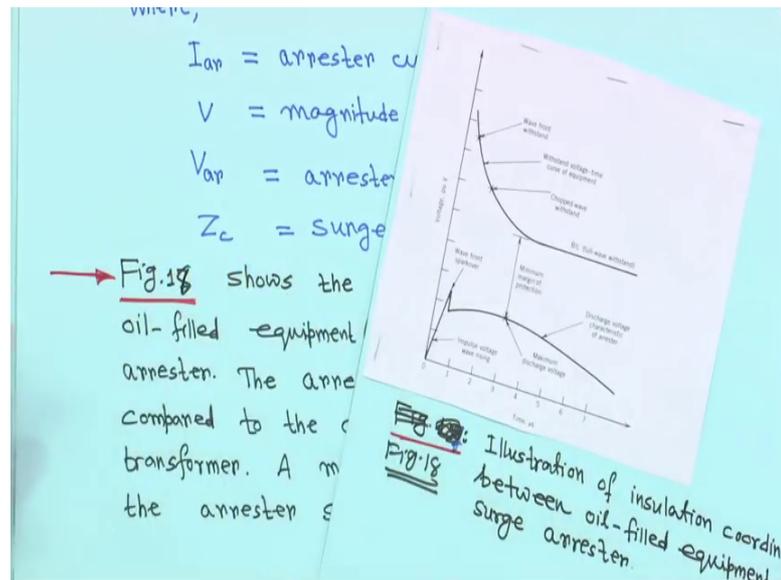
So, figure seventeen shows the insulation coordination figure 17 I will show you, shows the insulation coordination between an oilfield equipment for example, transformer and the surge arrester. The arrested impulse spark over voltage is compared to the chopped wave, test level of the transformer a more meaningful comparison is to compare the arrested spark over with the wave front test.

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That means, this is that your this is actually this is figure, it is figure 18, actually it should be figure 18, this is figure 18.

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So, in this case if you look into this that your wave front, this is that wave front withstand voltage. So, next is maybe it is reaching to your what you call at some withstand voltage time curve of equipment, then this is the chopped wave withstand, and this is the bill the following withstand, and this curve is discharge voltage characteristic of the arrester.

This is wave point spark over voltage, this side is voltage in per unit this side is the time in your microsecond, this is the impulse voltage wave rising it is rising, and this is your maximum voltage discharge at this point, because if you look in the curve this is the maximum voltage discharge, and this is the discharge voltage characteristic of the your arrester.

So, this is the minimum margin of the protection scheme, this gap is the minimum, this is the western voltage time curve of equipment chopped wave withstand right, at this point some of the wave is this is a chop wave withstand, and this wave from withstand. So, this is actually figure it in this is the illustration of the insulation coordination between oilfield equipment, and surge arrester this is this called the transformer right. So, all these things 1 has to your, 1 has to your, 1 has to your, understand he had not much mathematics here only little bit theory an understanding.

Thank you very much we will be back again.