Power System Protection and Switchgear
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Lecture 36
Arc Interruption Theory in Circuit Breaker - III

Okay. So, let us continue our discussion.

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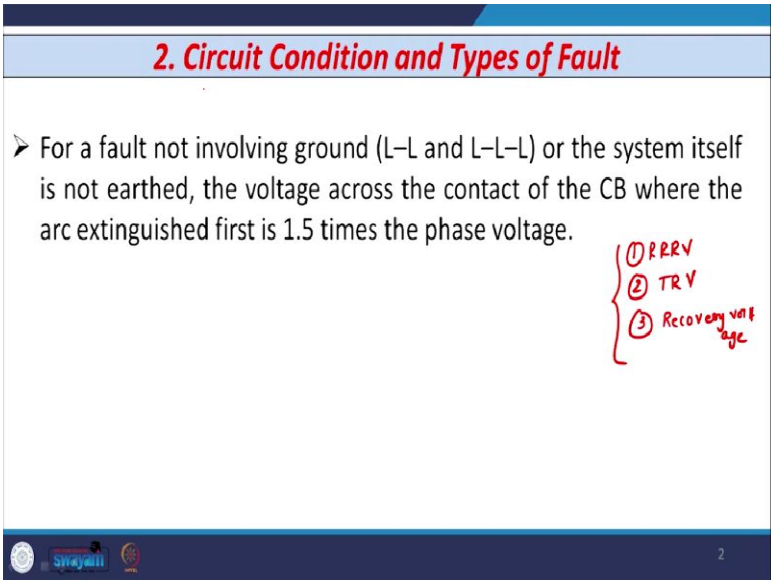

We have already discussed what are the factors that affect the three important terms. First term that is known as the, we have discussed that is the RRRV, the second term that is the TRV and the third term that is the recovery voltage. So, the second, we have already discussed what is the effect of power factor on the, these three important terms. We have discussed that when the power factor is low, the recovery voltage that is the voltage across the contact of circuit breaker that is high compared to when the power factor is high during normal and pre-fault condition.

So, let us discuss the second factor that is going to affect that is the circuit condition and the type of fault. If we consider a fault, let us say that this fault does not involve ground. So, it can be either line to line fault or it can be triple line fault. And at the same time, we also consider that the system is not earthed that means the neutral of the system that is isolated, the voltage across the contact of circuit breaker where the arc is extinguished first that is higher.

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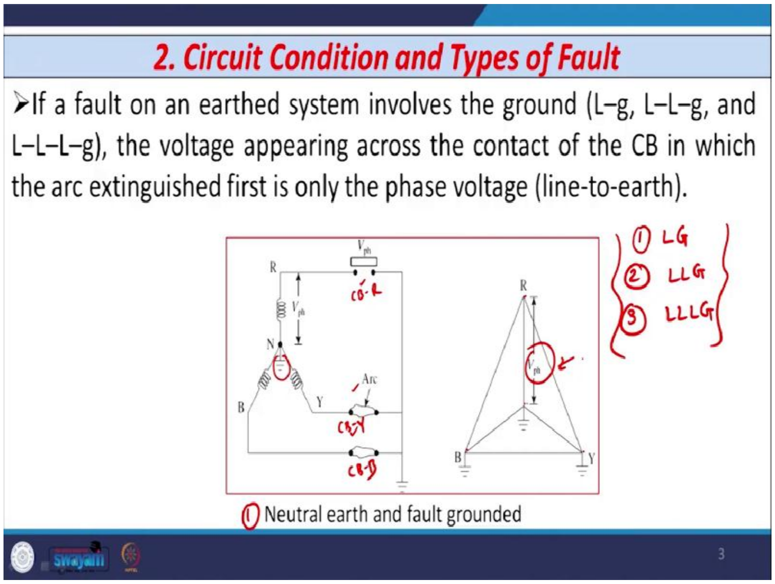

Let us discuss three different cases. The first case here we have considered, let us see this only the first case. You can see in the figure, I have shown this is the contact of circuit breaker in three phase, R, Y, B. So, this is CB-R, this is CB-Y and this is CB for B phase, so three poles of the circuit breaker. And the, here you can see that the neutral system itself is earthed. So, this earthling is there of the neutral and the fault is grounded fault that means fault involved ground. So it can be either line to ground fault or it can be double line to ground fault or it can be triple line to ground fault.

So, there are any of default, which involves ground, these are the three possibilities. And you can see that whenever such type of fault occurs, which involved ground and when the system neutral is earthed, then you can see that whatever voltage appears across the contact of circuit breaker in R phase, in Y phase and in B phase, those voltage is only the phase voltage. So, across the voltage, across the contact of circuit breaker of all the three poles that is only the line to earth voltage that is the phase voltage only.

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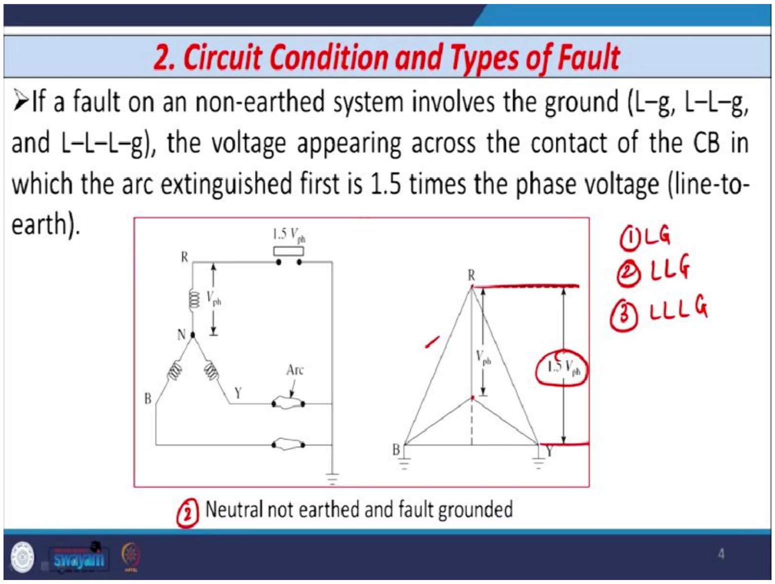

Now, if I consider the second case, where the, you can say that the neutral is not earth, so this is floating, it is not connected, and the fault that is also the grounded fault, so again it can be line to ground fault or it can be double line to ground fault or it can be triple line to ground fault. So, if this is the case, then you can see that in the vector diagram I have shown here the voltage appear across the, this value, across this point and this point you can see, it is not only the phase voltage, but it is 1.5 times the phase voltage.

So, in this case, when the, your neutral is not earthed and the fault that involves ground, then the voltage across the contact of circuit breaker, in which the arc is extinguished first. Now, we know that, there are three phase R, Y, B, so it may possible that the arc may extinguished in any of the one phase, then after certain interval, the arc is extinguished in other phase and then the third phase. So the voltage across the contact of circuit breaker in which the arc is first extinguished that is 1.5 times the line to earth voltage. So this voltage that has to be withstand by the contacts of the circuit breaker.

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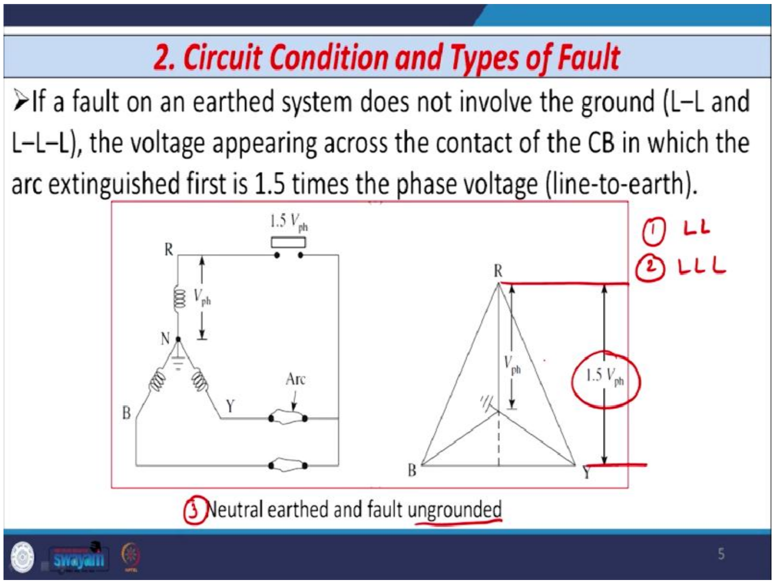

Let us consider the third case. In this case, you can see that the neutral is earth. So, here earthing is there, but the fault is ungrounded. That means, whatever fault occurs that does not involve ground. So it can be line to line fault or it can be triple line fault. So, in this case, when the system is not earthed and fault that does not involve ground L-L or L-L-L fault, then the voltage appear across the contact of circuit breaker in which the arc is first extinguish that is the 1.5 times again the phase voltage.

So, this voltage, if you again see, then it is 1.5 times the phase voltage and this voltage that has to be withstand by the contact of the circuit breaker. So, this is very important phenomena that whenever you design, carry out the designing of circuit breaker contact, the contact must withstand this much voltage.

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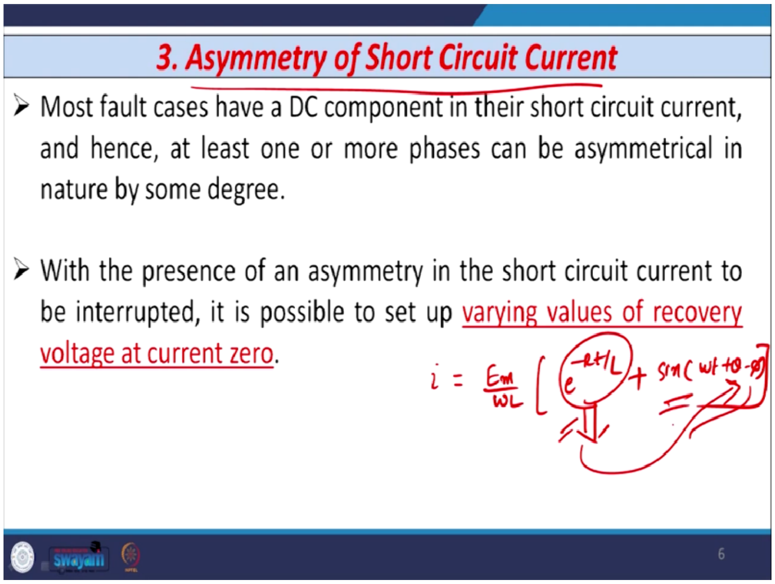

The third factor which is very important that is known as the asymmetry of short circuit current. Now, we know that whenever fault occurs, fault that can be either symmetrical or it can be asymmetrical. So, if symmetrical fault is there that means the triple line fault, it is a balanced fault. So, it has only positive sequence component. It does not have zero sequence and negative sequence term.

If fault is asymmetrical in nature on the other hand, then that is asymmetry depends on again at what instant the fault has occurred. So we have already described in earlier lectures or class that the instantaneous value of fault current that is given by the term Em by omega L or Z that is into e raise to minus Rt by L plus sin of omega t plus theta minus 5, where your theta that is the switching angle, phi that is the 10 inverse X by R line angle and this term that is the transient component that depends on the DC component, then it is also known as decaying DC component and this component depends on the switching instant theta.

So, in most of the cases when fault occurs, the DC component that is there in the short circuit current which is known as transient component, this is known as steady state component. So hence, at least one or more phases that can be asymmetrical in nature by some degree. So, with the presence of asymmetry in the short circuit current, which is to be interrupted at natural current zero, it is possible to set up a varying value of recovery voltage at natural current zero.

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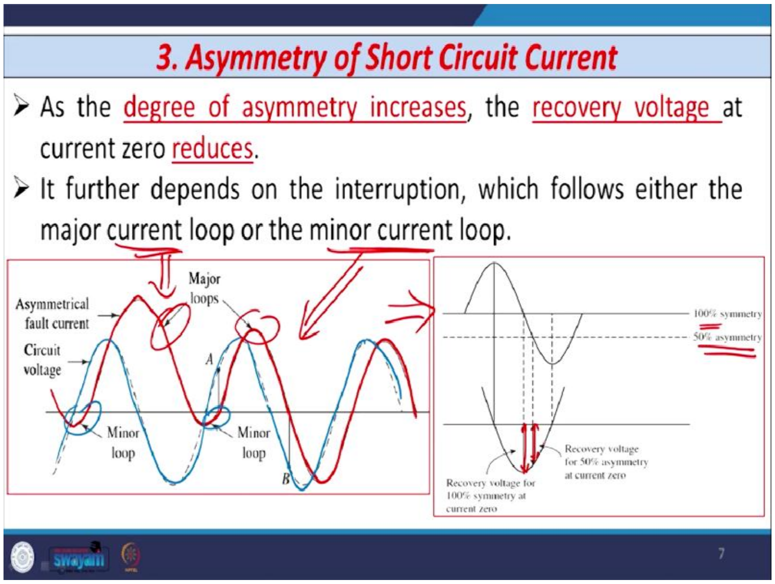

So, as the degree of asymmetry increases the recovery voltage at the natural current zero that reduces. And this is recovery voltage that further depends on the interruption, which follows either the, whether the interruption takes place at the major current loop or the minor current loop. So, this major current and minor current loop, you can consider in this figure.

So, you can see in this figure, in the waveform, that you can see the one waveform is of the asymmetrical fault current. So this is the wave shape of the asymmetrical fault current which is (conti) which is not sinusoidal and you can see the other wave shape that is for the circuit voltage that is the dotted wave shape that is this voltage that is the circuit voltage.

Now, you can see here, whenever the minor loop that indicates that the fault occurs somewhere here in this part, whereas the major loop that means the fault occurs somewhere here in this region. So, if fault occurs in major loop, asymmetry CT that is higher, if fault occurs in minor loop, then the asymmetry that is lower. The other way to understand this thing, you can see that, here again I have shown the two waveform.

The first waveform, you can see that is for 100 percent symmetry and below that x axis, I have also shown with dotted that is your 50 percent asymmetry. So, you can see that the recovery voltage when the symmetry is 100 percent that is this much, whereas the in case of 50 percent asymmetry, the recovery voltage that is comparatively lower. So, asymmetry CT exist in the short circuit current that is very important and that is going to affect the voltage that is appear across the contact of circuit breaker. Okay, this is all about the third factor that is going to affect the three terms RRRV, TRV and recovery voltage.

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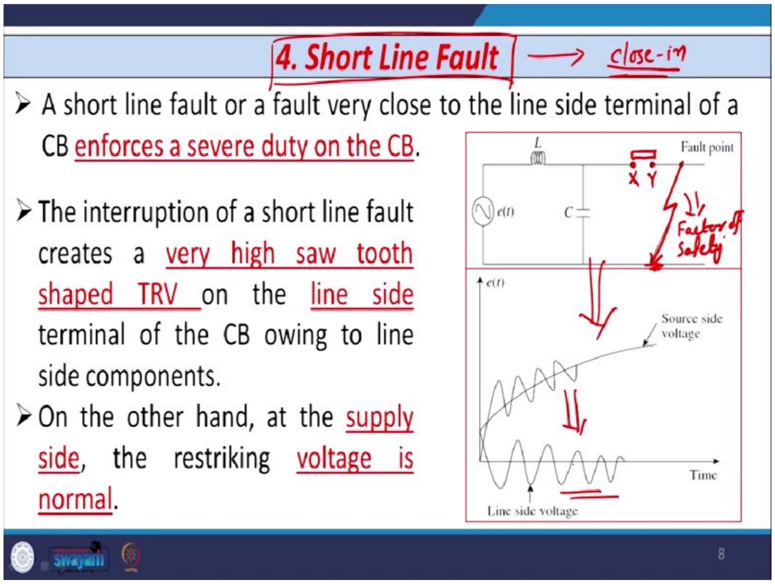

Let us discuss the fourth part that is the short line fault. This type of fault is also known as close-in fault, which occurs exactly immediately after the contact of circuit breaker. So these two are the contact of circuit breaker, let us say X and Y, this is one of the pole of the circuit breaker and immediately after that the fault occurs, this is known as short line fault or close-in fault.

So, whenever such type of fault occurs very near to the contact or pole of the circuit breaker, then the duty of circuit breaker that becomes very severe. So, in this case, you need to find out the term that is known as the factor of safety. So, you need to find out this term factor of safety. And then, according to the factor of safety, you need to decide the short time rating of the circuit breaker.

Now, the interruption of this close-in fault or short line fault that creates a very high saw tooth shape type transient restriking voltage on the line side of the circuit breaker, whereas if you look at on the supply side, then the restriking voltage that is normal. So here I have shown in the waveform, you can see this is the line side voltage, where the TRV is very high and goes on reducing, whereas on the source side voltage, again you can see the TRV that is almost not compared to that severe to the line side voltage.

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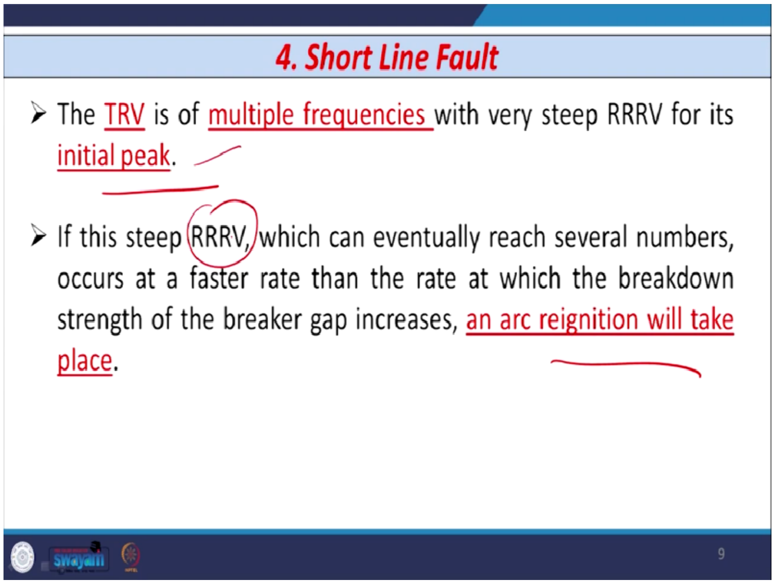

So, the TRV of the multiple frequencies with very steep RRRV that is there when you such type of fault that is to be interrupted by the contact of the circuit breaker. So, the initial peak of this TRV that is very high that is called as RRRV. If the steep RRRV that can eventually reach several numbers occurs at a faster rate than the rate at which the breakdown strength of the circuit breaker or the voltage or the gap of the circuit breaker increases, so the arc reignition that will take place. So, arc that is not going to be fully quenched and hence, re-striking of arc that occurs. So, the first peak of this TRV, which is the steep curve of RRRV that is also is going to create the problem for the circuit breaker and arc is not quenched fully and restriking of arc occurs.

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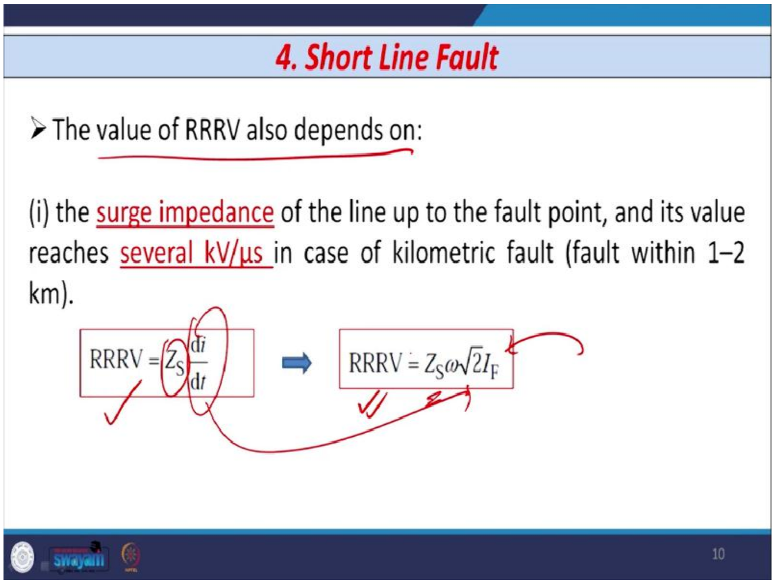

Now, how we can find out what is the value of RRRV in case of close-in or short line fault? So, whenever the such type of fault occurs, then the, this RRRV, value of RRRV depends on this surge impedance of the line from the source to the fault point and its value reaches of the several kilo watt per second or microsecond for a particularly fault which is very small length like 1 to 2 kilometer from the breaker.

So, in that case, the RRRV that is given by this value of the surge impedance into di by dt. And if you put this value of di by dt, then you will have the value omega root 2 into IF, where IF that is the magnitude of fault current, omega, angular frequency that you know. So, this is the value of RRRV that is going to appear across the contact of circuit breaker when very short line fault that is to be interrupted by the contact of circuit breaker.

Now, the short line fault whenever occurs, the short line fault test for a circuit breaker that is to be considered most severe and that is why I told you, you need to find out the factor of safety for such type of fault and you have to design the breaker accordingly. So, the test that is to be carried out or performed to prove the ability of circuit breaker to handle such type of extreme fault condition that is very useful while designing the circuit breaker particularly short circuit rating of the circuit breaker.

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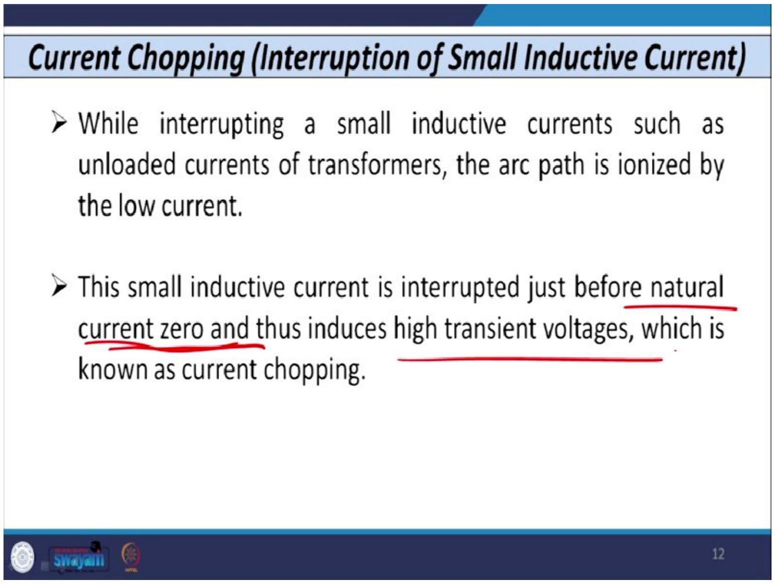

Now, let us see the next phenomena that is known as the current chopping. Current chopping is basically nothing but the interruption of small inductive current. So, this type of phenomena occurs when the small value of inductive current that is to be interrupted by the circuit breaker and the best example is the unloaded transformer. So, whenever the transformer is at no load condition, so secondary is almost open or very light load condition and when such type of current is interrupted when you energize the transformer, the such type of current that is to be interrupted by the breaker.

So, breaker that is faced difficulty to interrupt such type of current, even though the magnitude of such current that is very small, but the in this case the voltage appear across the contact of circuit breaker that is very high. So, the small value of inductive current that is interrupted, why this is, what is the reason, because whenever the magnitude of the small inductive current that is very small when you just energize the unloaded transformer, at that time the current that is to be interrupted just before the natural current zero. This is very important.

So, when the interruption of small inductive current takes place that current is not interrupted at natural current zero, but it is interrupted before the natural current zero and because of this a very high transient voltage that is going to appear across the contact of circuit breaker. So, this phenomenon is known as current chopping phenomena.

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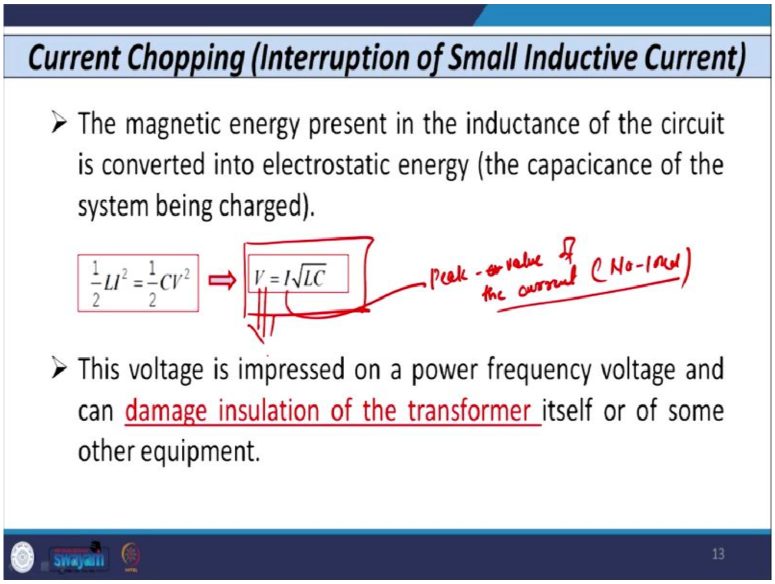

So, in this case, particularly, why it is very severe or difficult, because the magnetic energy present in the inductance of the circuit that is converted into the electrostatic energy because the capacitance of the system that is being charged. So, in that case, the one-half LI square energy in inductance of the circuit that is transferred to the electrostatic energy if we consider the capacitance of the system that is one-half CV square. And if you find out the voltage, then the voltage in this case that is given by the current.

This current I, that is the peak value of the current, peak value of the current. And this current is basically nothing but your no load current, because as I told you, when you energize the unloaded transformer, when transformer is on no load condition, so that is why this current is the no load current and you find out peak of the no load currents that is this current and L and C are the parameters of the circuit.

So, whenever this voltage V, you can calculate it, this voltage that is going to be appear or impressed on power frequency voltage that is our steady state voltage and whatever is the total voltage that is going to impair or damage the insulation of the transformer itself or may it may sometimes damage the other insulation of other associated equipment also, so that is why whenever such type of small inductive current is interrupted by the breaker, then we need to take care at the time of design of the circuit breaker.

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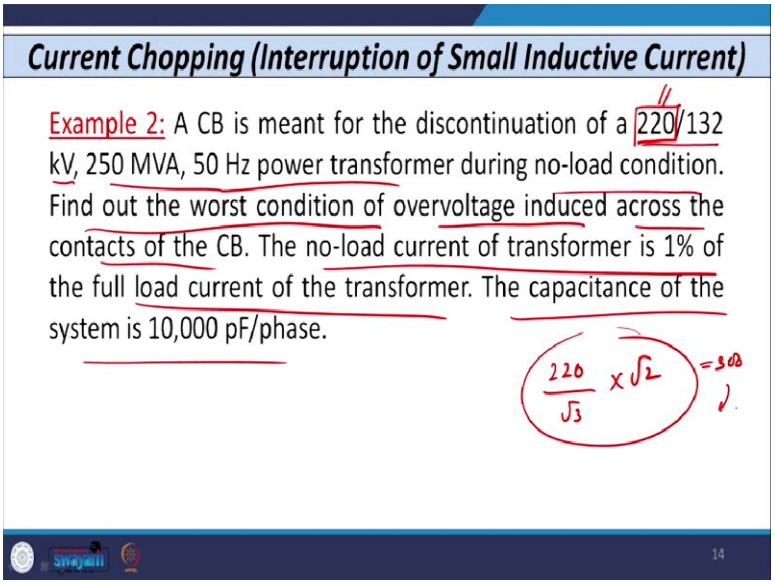

Now, let us consider, what is the value of the current to be interrupted and what is the voltage appear across the contact of circuit breaker. To understand this, let us consider one example. So, in this example, circuit breaker that is mean for the disconnection of 220 kV by 132 kV, 250 MVA, 50 hertz power transformer and this transformer is in no load condition and you energize the transformer and this current, whatever current draws by it that is to be interrupted by the breaker. So, you need to find out the worst condition of overvoltage induced across the contact of circuit breaker assuming that the no load current of the transformer is 1 percent of the full load current of the transformer and the capacitance of the system that is 10000 pico Faraday per phase. So, let us solve what is the voltage appear across the contact of circuit breaker.

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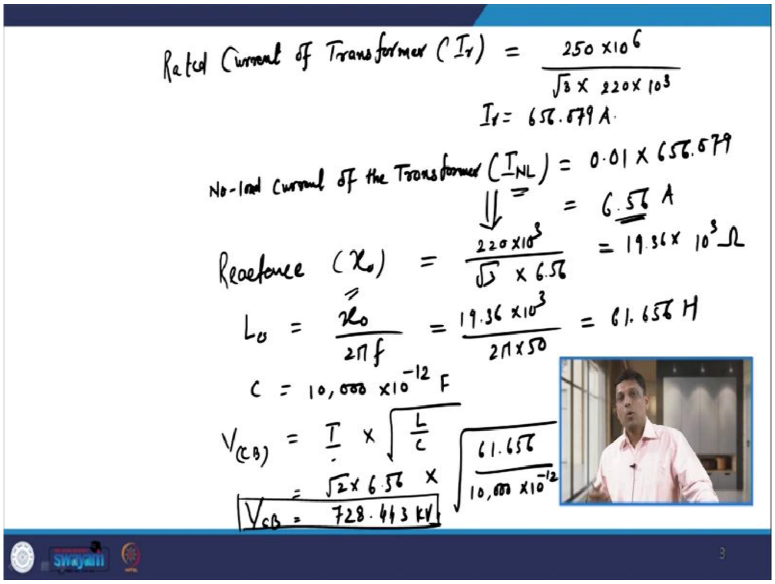

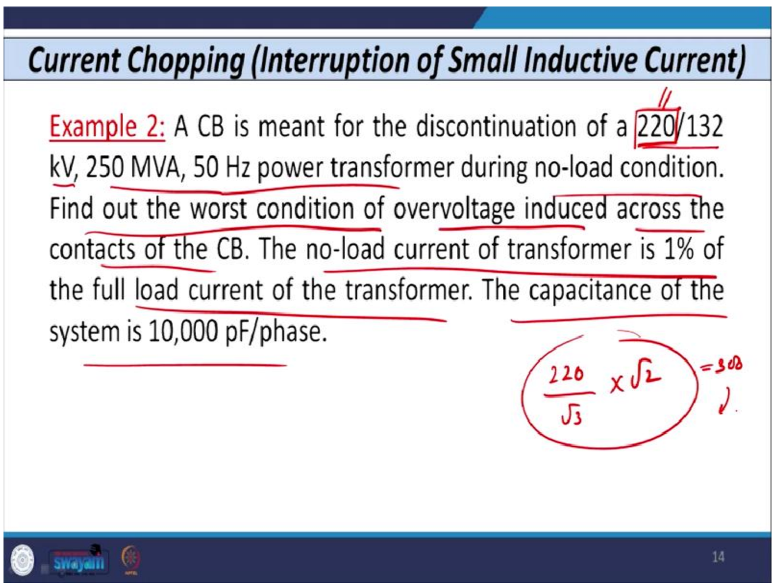

To solve this, let us first consider or find out what is the rated current of the transformer. So, if I find out the rated current of the transformer, let us call it Ir, then that is equal to, as I told you, 220 kV is on primary side, the 132 kV that is on secondary side, which is open. So, the no load current that is the rating of the transformer is 250 MVA. So, 250 into 10 raise to 6 divide by root 3 into voltage rating that is on primary side, 220 into 10 raise to 3. So, if you calculate the value that comes out to be 656.079 ampere. So, this is the rated current of the transformer.

Now, let us find out what is the no load current of the transformer. So, it is mentioned that the no load current of the transformer is 1 percent of the full load current of the transformer. So, the no load current of the transformer that is let us call it I no load that is equal to 1 percent that is 0.01 into 656.079. So, roughly it is 6.56 ampere. This is how we have calculated the no load current of the transformer.

Now, with this no load current, let us find out what is the reactance that is X0, let us call it, which is nothing but this we can calculate from the system voltage. So, the voltage is 220 kV, let us make it phase voltage and divide it by the no load current which is 6.56. So, if you calculate this value that comes out to be 19.36 into 10 raise to 3 ohm. So, let us find out what is the L0 that is X0 by 2 pi f. So, if you divide this value 19.36 into 10 raise to 3 divided by 2 pi into f that is 50 hertz. So, that comes out to be 61.656 henry. So, L you have calculated. The value of C that is already given. So, it is 10,000 pico Faraday.

So it is 10,000 pico Faraday. So 10 raise to minus 12 farad, it is already given. So, let us find out what is the voltage appear across the contact of circuit breaker that is nothing but the I into under root L by C. This I that is the peak value of no load current. So, if I just write down, what is the peak value of no load current? It is root 2 times 6.56 into square root of L that is 61.656 divided by 10000 into 10 raise to minus 12. So, if you calculate this value then it comes out to be this 728.443 kV. So, this is the voltage that is going to be appear across the contact of circuit breaker, when such type of small inductive current that is to be interrupted by the breaker.

So, you can see that the voltage on the primary side that is 220 kV and if I assume that the voltage that is withstand by the breaker is 220 by root 3 into root 2 this value. So, this is almost value something 300, right, which is always the lower than the voltage, which we have calculated 728 kV. So, obviously if such voltage that is going to appear across the contact of Circuit Breaker and breaker that is definitely going to damage. So, insulation of the transformer or maybe some other associated equipment that is damaged.

So, with this background, let us see how the current Chopping phenomena, how such type of very high voltage that is going to appear across the contact of Circuit Breaker. So, the principle to calculate this voltage across the contact of circuit breaker during current chopping, that is basically nothing but the energy conversion that is going to take place before and after the arc extinction.

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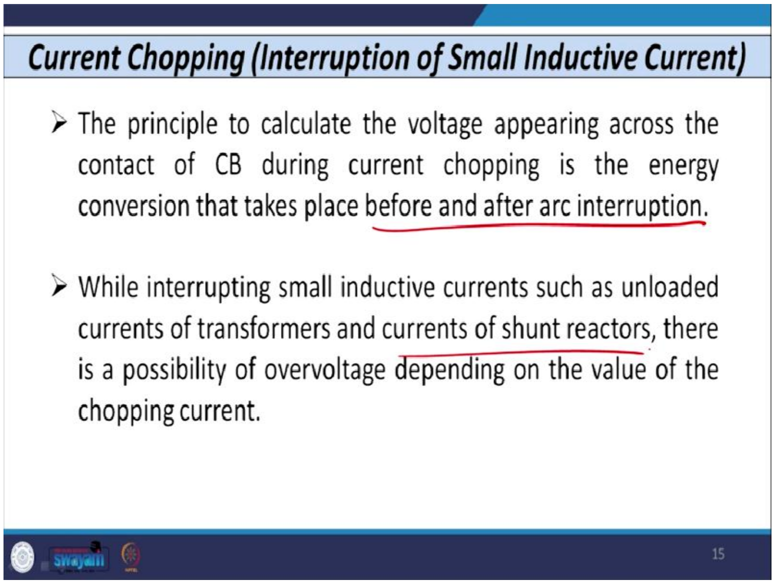

So, this is very important and while interrupting such as smaller inductive current, particularly no load current of the transformer. The other example is the shunt reactor, when such current is interrupted by the shunt reactor, then there is a possibility of over voltage because of the chopping phenomena.

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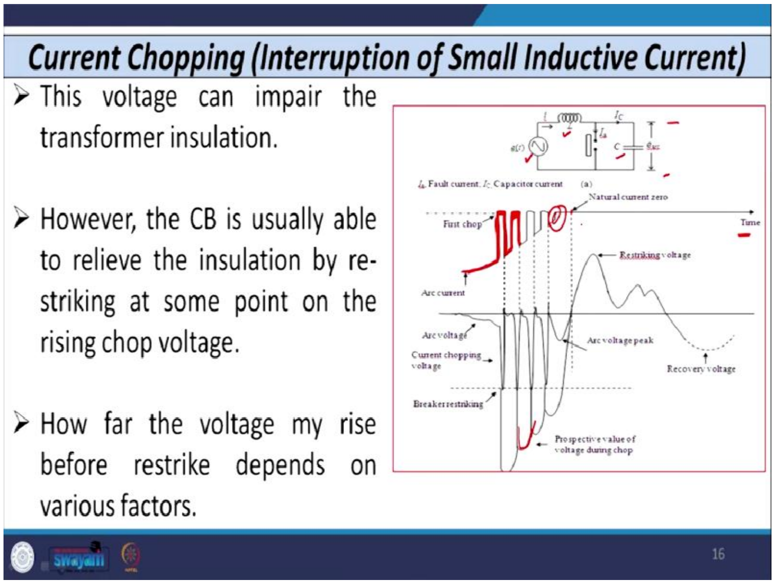

Now, how this chopping phenomena occurs. So, you can see that on this figure I have shown here two; one is the main circuit where you have the source then the L and C parameter and the voltage that is going to appear. And you can see I have also shown the waveform that is on time axis and the current and voltage also I have shown.

So, you can see that the upper side, I have shown the arc current. So, arc current that is, see the natural current zero comes somewhere here and before the natural current zero comes here the arc current that is chopped here like this and this. So, this chop is the first current chop. So, at this instant during the first current chop, you can see the arc voltage is also given and the voltage that is going to appear across the breaker or Restriking Voltage that is also there.

So, during first current chopping the magnitude of current is high, voltage is also high. So, the arc which is appeared across the contact of circuit breaker, the dielectric medium that is going to just quench the arc and because of that if that whatever as I told you according to Slepian or Cassie's Theory that phenomena is not satisfied. Then there are chances of restriking of arc.

So, during restriking the other chopping takes place which is in this case, the magnitude of current is lower than the first chop and hence, the voltage is also slightly lower, you can see here. So, as successively the chopping takes place and as you move towards the natural current zero, you can see in this region the magnitude of current is very small, the voltage that is also very small. So, you can see that after several chopping instance the current that is to be chopped but at that same time, the voltage appear across the contact of Circuit Breaker that is very high.

You can say that this whatever voltage appear are available across the contact of Circuit Breaker it may damage the insulation, transformer insulation. However, Circuit Breaker is usually able to relieve the insulation by restriking. So, as I told you, there are several restriking takes place the, it means how much voltage that will rise before the restrike that depends on several factors.

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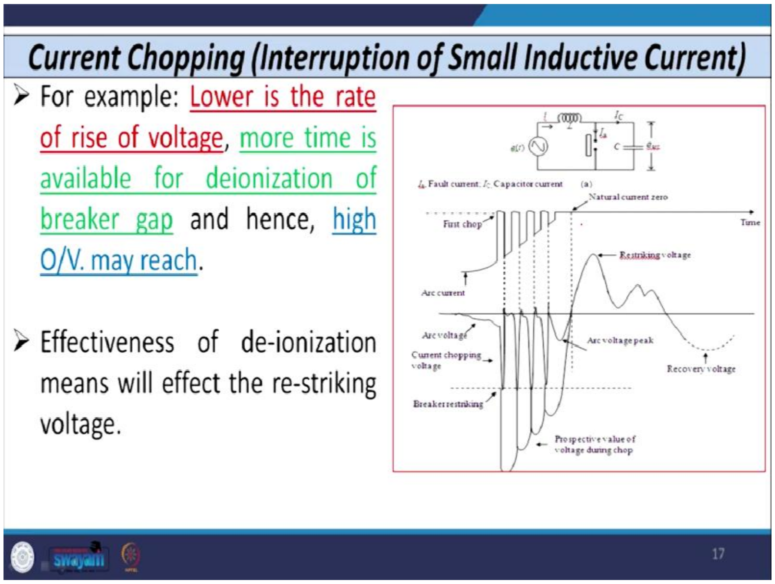

Say one of the factor is for example, if lower is the Rate of Rise of Voltage, more is the time available for deionization of the breaker gap and hence the high over voltage that may reach. The other is the, what is the effectiveness of the deionization means, means what is the dielectric strength of the medium, insulating medium, which you have used in the breaker, that also plays an important role.

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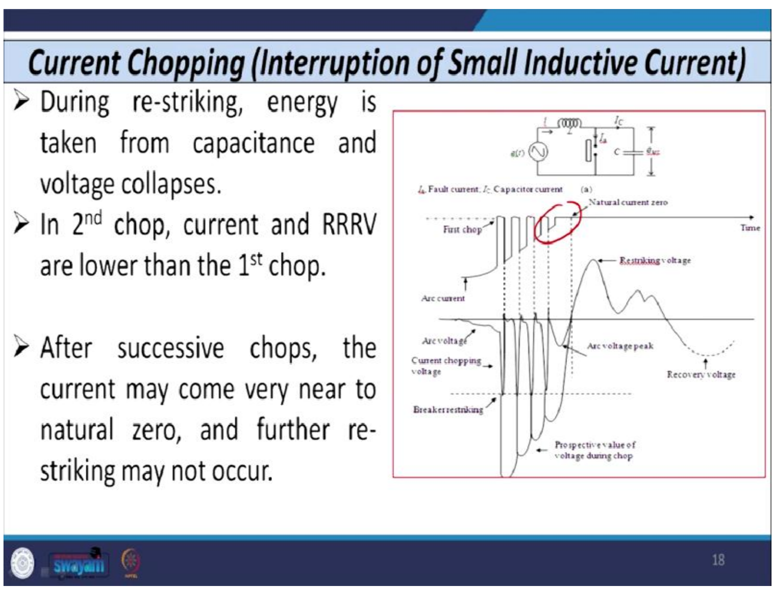

So, during restriking energy that is taken from the capacitance and the voltage then collapses reduces as the successively the chopping states occurs. So, after several choppings, the current may have come very near to the 0. In this portion you can see and further restriking that may occur and after several instant the arc that is fully quenched and then, the voltage across the breaker that has to be withstand by the contact of the Circuit Breaker.

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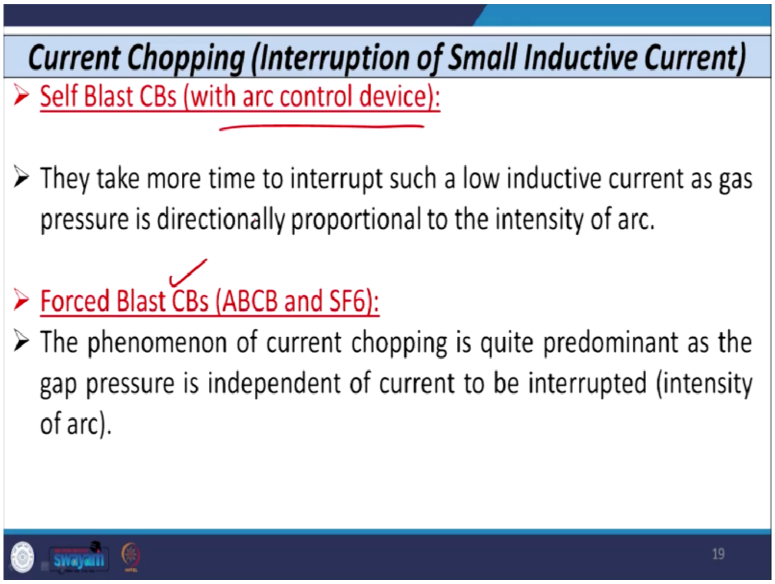

So, if I consider the Self Blast Circuit Breakers, which are equipped with arc control device, like the previous Air Blast Circuit Breaker and Oil Circuit Breaker, they take more time to interrupt such type of small inductive current, because the gas pressure is directly proportional to the intensity of arc. So, when the intensity of arc is very small because the current interrupted that is also very small. So, the gas pressure is also very small. Whereas, in case of Forced Blast Circuit Breaker like Air Blast Circuit Breaker and SF6 Circuit Breaker, the phenomena of current chopping is quite predominant as the gas pressure is independent of current to be interrupted. So, it is independent of the intensity of arc.

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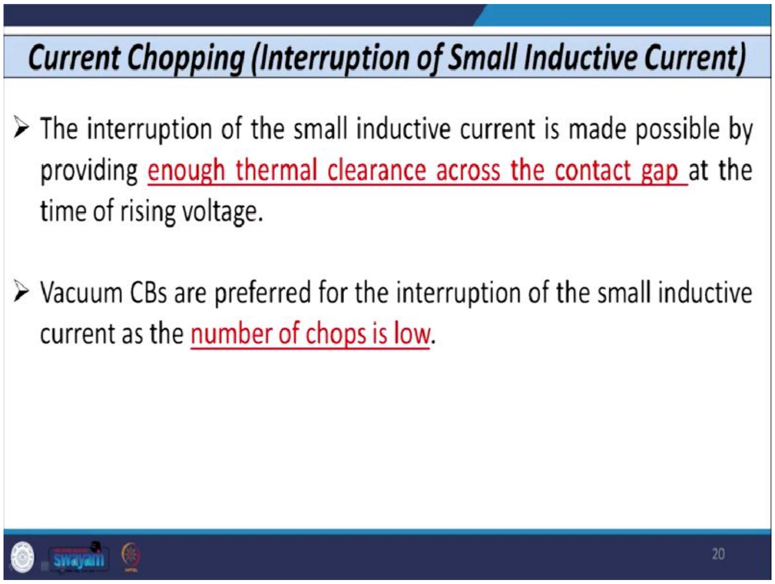

So, the interruption of small inductive current when this type of phenomena is there then this type of phenomena that is made possible by providing enough thermal clearance across the contact gap of the breaker at the time of arising voltage. Vacuum Circuit Breaker that is normally preferred when such type of current that is to be interrupted because the number of jobs that is very low compared to the SF6 and some other types of Circuit Breaker. So, that is why Vacuum Circuit Breaker is more preferred when there is a need to interrupt this small inductive current, best example is the interruption of such type of current by unloaded transformer.

So, in this class, we have discussed the several factors that is going to affect the three terms RRRV, Recovery Voltage and Transient Restriking Voltage that is the circuit condition and is asymmetry, the Short Line Fault or close-in fault. And then we started the discussion with the Current Chopping phenomena, that is when the small inductive current is interrupted, then the very high voltage that is going to appear across the contact of Circuit Breaker and breaker is capable to withstand that value that is there. So, I stop here and we will continue further in the next class. Thank you.