Power System Protection and Switchgear
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Lecture 37
Arc Interruption Theory in Circuit Breaker-IV

Okay, so let us continue our discussion on what are the problems faced during, by the Circuit Breaker during the interruption of an arc. So, we have already discussed, the interruption of small inductive correct by the Circuit Breaker, this is the, example is the energization of unloaded transformer. So, let us discuss the other case that is the interruption of capacitive current.

Now, we know that whenever the capacitive currents that is to be interrupted by the Circuit Breaker, this is also interrupted at the natural current zero by the breaker. But in this case, the phenomenon is, means that whatever voltage is build up or appear across the contact of Circuit Breaker that is slightly different.

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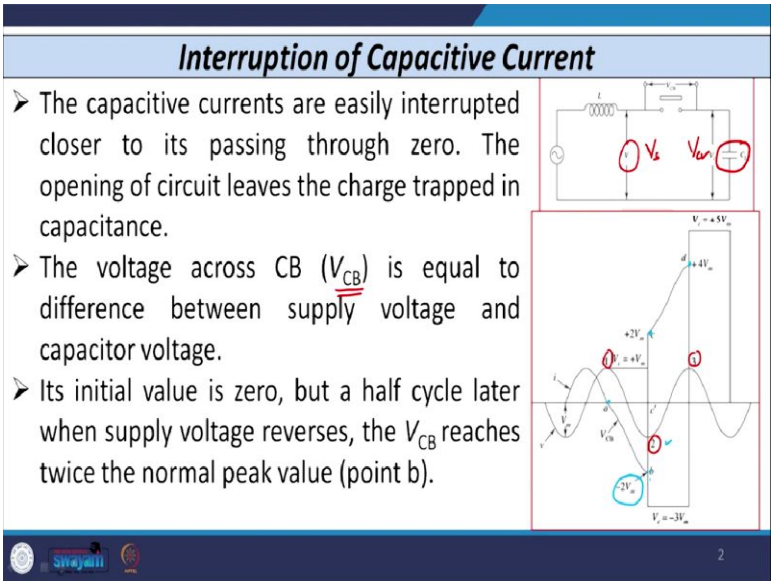

So, the opening of Circuit Breaker, because in this case the Circuit Breaker is there that is here and the opening of the circuit that leaves the trap charge on the Circuit Breaker and that trap charge which is on this side that is responsible for the increase in voltage across the Circuit Breaker. You can see that the voltage across the Circuit Breaker that is known as the VCB that is

equal to the difference between the supply voltage that is here supply voltage VS and the capacitor voltage that is the VC.

So, this voltage that is VC. So, if you take difference of these two that voltage that is going to appear across the contact of Circuit Breaker and that is given by VCB. Now, when you consider this value of VCB that is normally zero, initial value is zero. So, you can see the waveform is also given here that is the voltage and current waveform with reference to time.

Now, you can see, I have also marked the similar points like the point A that is here, then the point B that is here, and further some other points like C point and D point. And on the voltage waveform, I have marked that the point like the point number 1, the point number 2, point number 3. So, you can see there is a difference and if I just see this waveform and you can see that whenever you have the one point here that is A, another point here B, another point is here C and the other point that is D.

Now you can see that after immediately this point, point A, the supply voltage that is the wave shape that reverses and it becomes a negative. So, its peak value that is a negative peak value that is at point number 2. So, at this point, the voltage across the Circuit Breaker that is nothing but the voltage V that is the supply voltage minus of the voltage across this capacitor that is C. So, the total voltage at this when supply voltage becomes negative, at it its negative peak then the value of VCB that becomes minus 2 VM at point B.

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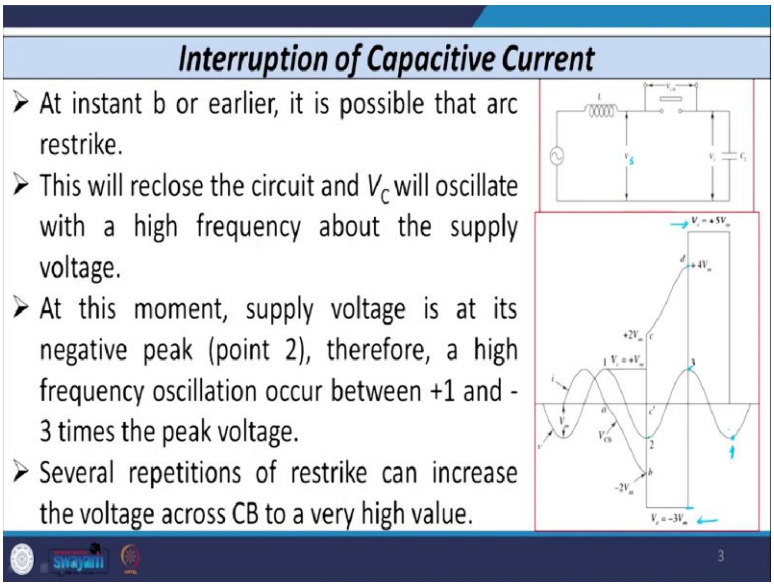

Now, immediately after that what will happen there are fair chances of restriking of an arc. So, wherever the arc restrike that means the reclosing of the circuit that occurs. So, the voltage across the capacitor that is VC that is going to oscillate with a high frequency of this about the supply voltage. So, in this case, what will happen the voltage at point 2 if you see the voltage is at its negative point and then, after at this point the frequency of oscillation that is from the plus VM to minus 3 VM. And as you move further, again if you go for another half cycle at this point, again the oscillations that will be from this point to this point.

So, as you move further from point 2 to point 3 to again the point 4 somewhere here. So, as you move every half cycle, the voltage that is going to appear across the contact of Circuit Breaker that is VCB that goes on increasing and this is because the voltage across the capacitor VC that is going to oscillate with some high frequency value and because of this, the overall voltage across the Circuit Breaker that is the difference of supply voltage VS minus this VC. So, that voltage also going to increase.

Ideally, if we want to say we can say that the voltage across this contact of Circuit Breaker that is going to be doubled at every half cycle. So, as you move from point 2 to point 3, this is also one half cycle, point 3 to point 4 again half cycle, so, the voltage becomes a doubled. But practically,

as the resistance of the source as well as the line that is also comes in picture. So, this value is not exactly double, it is lower than that value.

After several repetitions of restrike, restrike can increase the voltage (acro) so voltage across the contact of Circuit Breaker that becomes very high and this circuit breaker or the contact of Circuit Breaker has to withstand such type of very high value, particularly when the breaker, a value that is interrupted by the breaker then in this case breaker whatever voltage appear across the contact of Circuit Breaker, Breaker has to withstand that value.

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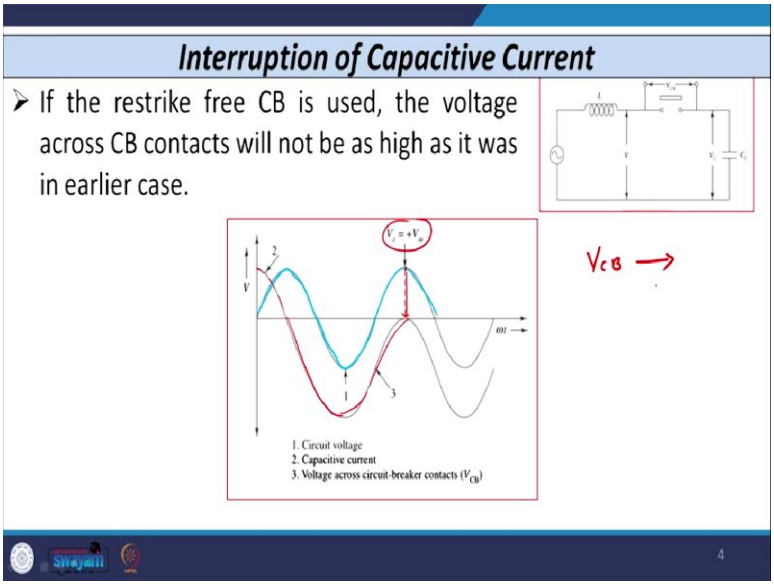

If you use restrike free Circuit Breaker like Vacuum Circuit Breaker and some other circuit breaker, then the voltage that is going to appear across the contact of Circuit Breaker that is not as high as it was in the earlier case or previous case. So, you can see the waveform where you can see the first this part A that is the supply voltage. So, this is your supply voltage and you can see the other waveform that is of the current waveform. So, you can see this is the capacity of current waveform and you can see at this point the voltage across the VCB that is only the maximum value that is VM only. It is not going to doubled after every half cycle immediately after the interruption of short circuit current by the breaker.

So, this is all about the capacitive current. So, wherever as we have discussed the circuit breaker that is going to installed and whenever the breaker has to interrupt either small inductive current

or small capacitive current, the voltage across the contact of circuit breaker that is very high and breaker has to withstand that value. So, whenever you design the circuit breaker such type of point that needs to be considered while deciding the short time rating of the Circuit Breaker.

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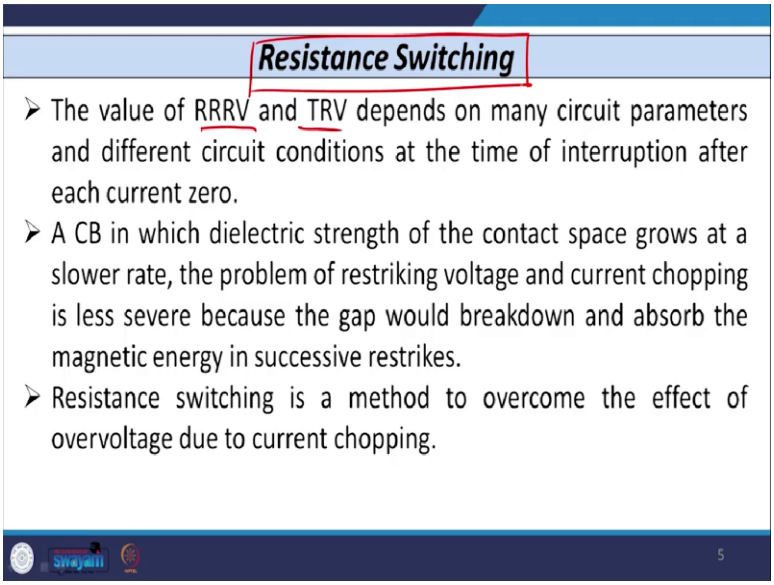

Now, after this, one very important point is how to reduce, practically how to reduce such type of the voltage which is going to appear across the contact of Circuit Breaker. So, if we suppose assume that as we have discussed there are three important terms related to the circuit breaker means, wherever the current or short circuit current is interrupted by the breaker there are three important terms one is known as RRRV, Rate of Rise of Restriking Voltage, other is the Transient Restriking Voltage, TRV and the third one is the recovery voltage.

So, if I want to reduce this voltage appearing across the contact of circuit breaker while interrupting either small inductive current or capacitive current, then the how to reduce that? So how to reduce the voltage across the breaker, which is going to appear at the time of the interruption of short circuit current?

So, this can be achieved with the help of the term known as Resistance Switching. So, now, we know that, what is Resistance Switching. So, Resistance Switching is a method that is used to overcome the effect of the voltage that is going to appear across the contact of Circuit Breaker

while breaker is interrupted maybe small inductive current or small capacitive current or some other short circuit current.

So, this point is very important and we know that the Circuit Breaker in which the dielectric strength of the gap between the contact of Circuit Breaker that is that grow means dielectric strength across the contact of Circuit Breaker increases slowly then the problem of restriking voltage and current chopping that is less severe that is not as severe in earlier case because the gap would break down and that will absorb the energy from the when the successive restrike occurs. So, after every restrike whatever energy is there in the arc that is to be absorbed by the breaker itself. So, that is why it is not as severe.

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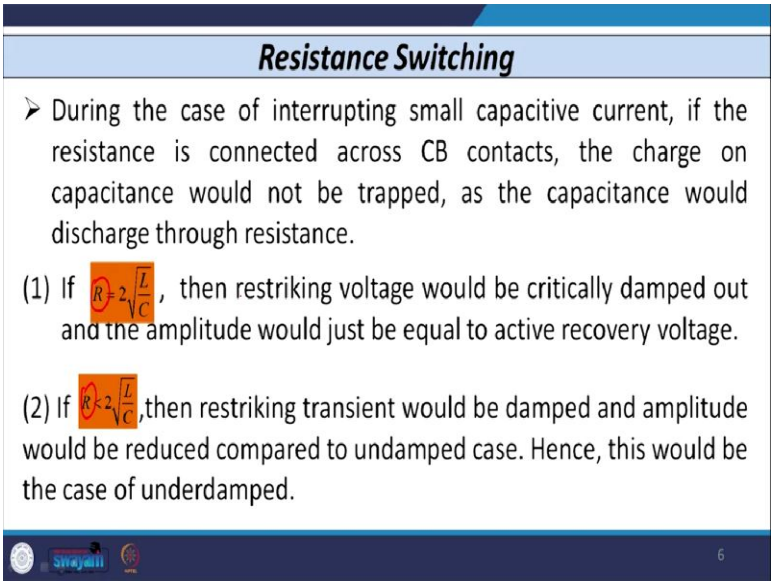

Now, let us see how we can utilize the Resistance Switching to reduce the voltage appear across the contact of Circuit Breaker. So, while the interrupting small capacitive current, if the resistance is connected across the contact of the Circuit Breaker then whatever charge that is going to be appear on the or that is going to trapped on the capacitor that charger does not remain there and it is going to be discharged through the resistance which we are going to connect in parallel with that. So, the question comes what value of resistor we connect across the contact of Circuit Breaker. So, we can connect the value or we can decide the value of R maybe by parameters of this system and line that is the L and C.

So, if I use the value of R that is equal to 2 into under root L by C, then whatever is restriking voltage appear across the contact of Circuit Breaker that is of critically damped shape and the amplitude that will be almost equal to the recovery voltage, you know that recovery voltage is the steady state power frequency voltage, immediately after the extinction of arc. If I consider the value of R that is lower than this to 2 into under root L by C value, then the whatever restriking voltage is there that is damped in nature and again, the amplitude that would be reduced compared to the earlier case. So, this is also the case of underdamped.

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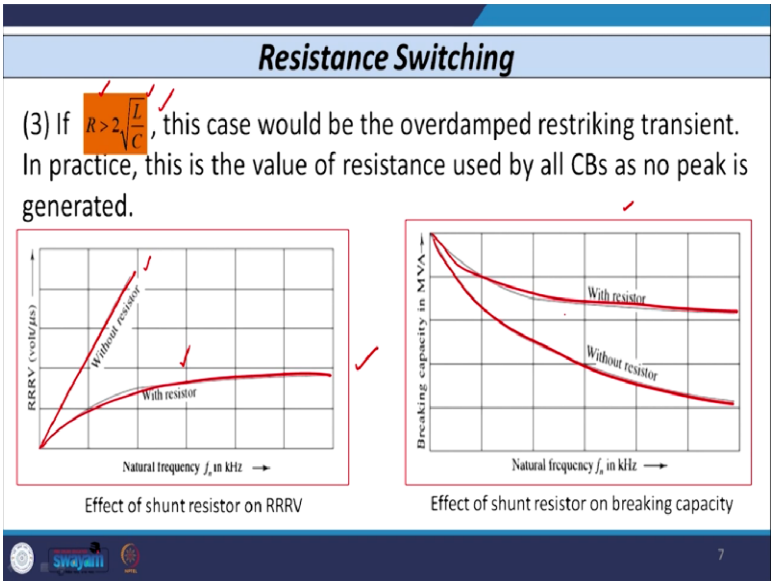

And the third case if I assume, R is greater than the 2 under root LC, then this case that would be overdamped restriking case and this type of value that is R, the value of R is greater than this value that is actually used in practice, because in this case the no peak is generated as it was generated in earlier 2 cases. So, again, these whenever the steady state value that is established or achieved that is achieved without any peak.

So, the first a peak of the RRRV that is not there. So, the Transient Restriking Voltage that is not very severe. So, that is why they use the value of R and then you connect it in parallel with the contact of Circuit Breaker. Now, if I use the resistor or if I not use the resistor across the contact of Circuit Breaker, then let us see what is its effect on the Rate of Rise of Restriking Voltage as well as the breaking capacity of the Circuit Breaker.

So, you can see, the graph where the natural frequency of oscillation that is considered in kilo hertz on the X axis and the RRRV that is volt per microsecond that is considered on Y axis. And you can see, if I do not use the resistor, the value of RRRV is like this, as you increase this value, the RV also increases. Whereas, if I use the value of R maybe have this value across the contact of Circuit Breaker, then the RRRV value that becomes steady after some point of time.

So, the RRRV that reduces compared to this point, it becomes like this. Same way, you can see the other graph, where I have plotted the natural frequency of oscillations in kilohertz versus the breaking capacity of Circuit Breaker in MVA. So, you can see that without resister the breaking capacity that is lower compared to if I use the resistor then the breaking capacity of Circuit Breaker that is higher than the previous case.

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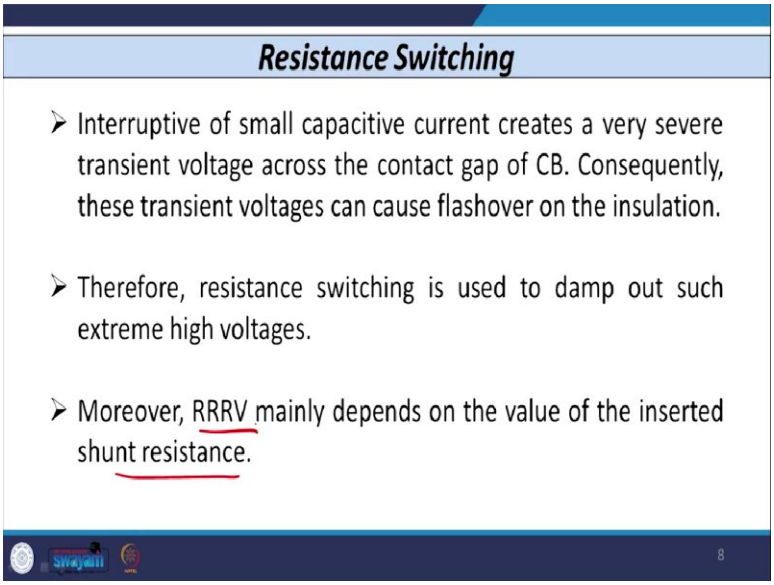

So, we can say that if I, that means if the interruption of small capacitive current that is to be carried out by the breaker, then this interruption creates a very severe voltage across the contact of Circuit Breaker or across the gap. So, this transient voltage that may lead to the flashover of insulation. So, that may damage. So, if we wish to avoid it, we have to use the resistance switching maybe of some particular value and if I use that then that can easily damp out such type of high voltages.

And as we have already discussed through the graph that the Rate of Rise of Restriking Voltage that usually depends on the inserted shunt value of the resistance. So, if I connect the resistance, in parallel with the contact of Circuit Breaker, then the value of RRRV reduces and the value of breaking capacity of Circuit Breaker that becomes better.

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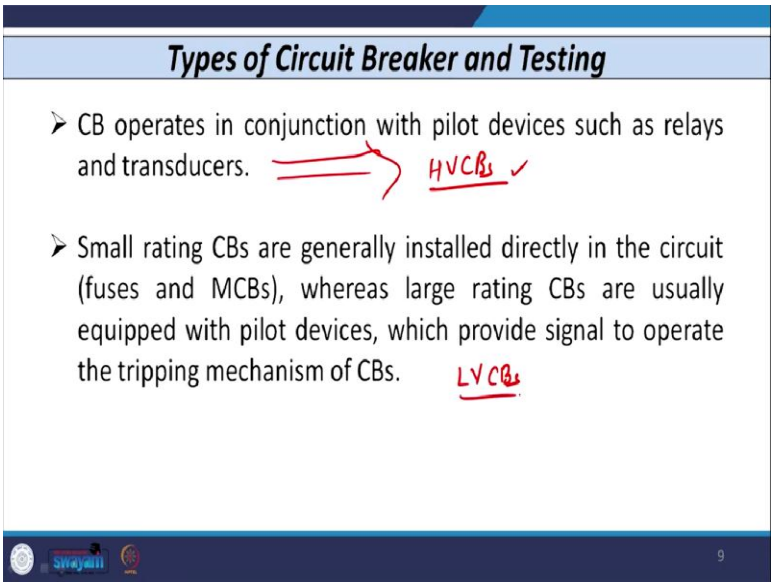

So, with this background now, let us discuss what are the different types of Circuit Breaker and how the testing of this Circuit Breaker that is to be carried out. So, we know that the Circuit Breaker operates that is in conjunction with the other protective device like relays, maybe some CT, PT or maybe transducer also. Whereas, these all such type of breakers are known as the High Voltage Circuit Breakers.

Whereas, if I use the Low Voltage Circuit Breakers then this type of Circuit Breakers that is generally installed directly into the field or at particular place wherever you need the protection and the type of such pilot devices is like relays, transducers, those are not required even the tripping mechanism, which that is required in High Voltage Circuit Breakers that is also not required in this type of Circuit Breaker, these are known as the Low Voltage Circuit Breakers.

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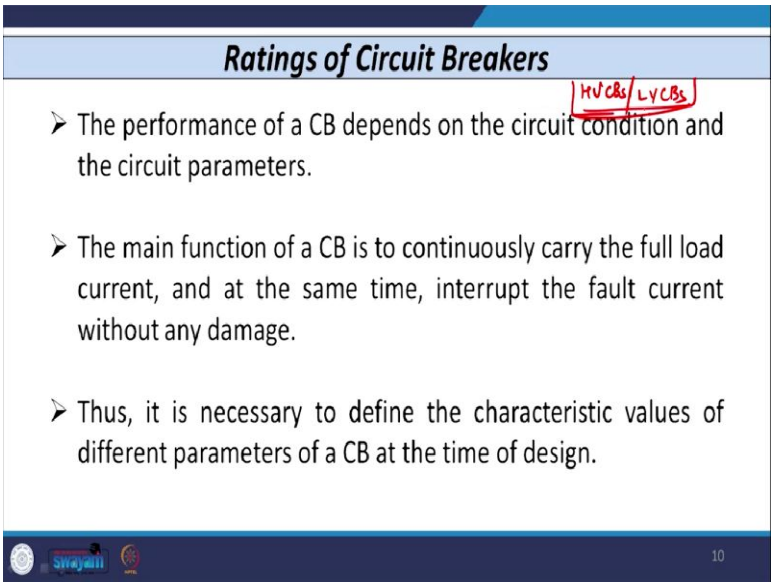

So, with this background let us first discuss, what is the rating of Circuit Breaker. So, this we will discuss about the High Voltage Circuit Breakers. However, it can be also applicable to Low Voltage Circuit Breakers also maybe the definition that may change slightly, in case of Low Voltage Circuit Breakers.

Now, the performance of Circuit Breaker that mainly depends on the parameters of the circuit where you are connecting the breaker as well as the what is outside circuit condition. So, the main function of Circuit Breaker that is it has to continuously carry the full load current without any temperature rise and also it has to interrupt the short circuit current without any damage. So, this is the main duty of the Circuit Breaker. So, that means, we have to define some characteristic value of the breaker based on certain parameters.

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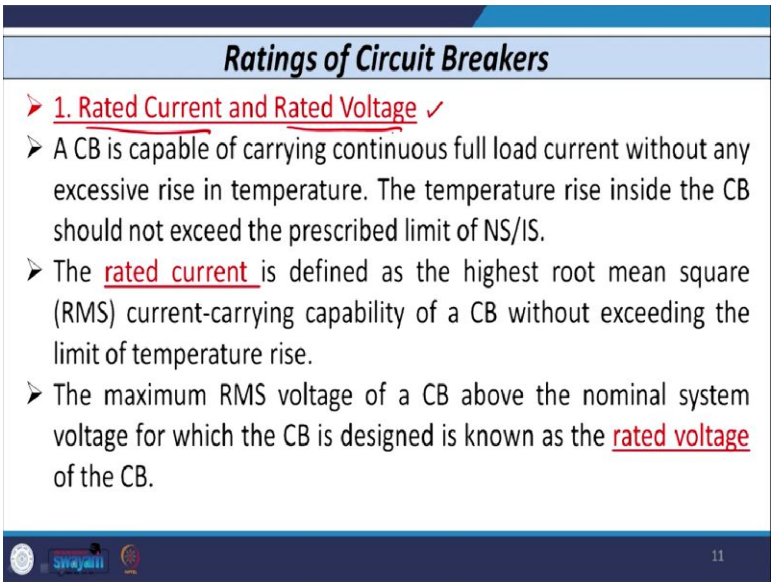

So, let us discuss what are the different, some standard nomenclature or some standard definitions that is used for the Circuit Breakers. So, the first point that is known as the Rated Current and Rated Voltage of the Circuit Breaker. So, as we have already discussed that the Circuit Breaker is capable to carry the continuous full load current plus some with some over percentage overload without any temperature rise and this temperature rise that is clearly mentioned in the national or international standards.

So, as per some standards it is ensure that whenever breaker is installed it has to carry full load current without any temperature rise. So, if I just want to define the Rated Current of the Circuit Breaker then it is defined as the highest RMS value or the current carrying capability of Circuit Breaker without exceeding the whatever limits defined by the standard of the temperature rise. So, this is nothing but the Rated Current of the breaker.

Whereas, if I wish to define the Rated Voltage then rated voltage of the Circuit Breaker is defined as the maximum RMS voltage of a Circuit Breaker above the system voltage or nominal system voltage for which the Circuit Breaker is designed that is known as the rated voltage.

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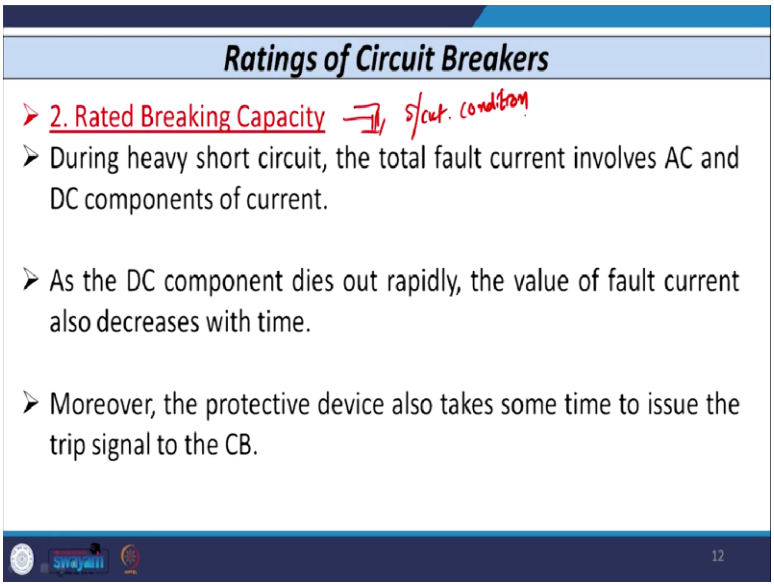

Okay, so, the second point that is known as Breaking Capacity or the Rated Breaking Capacity of the Circuit Breaker. Now, this definition that comes picture again under the short circuit condition. So, we know that during heavy short circuit, the total fault current that involves the transient component that is the decaying DC component as well as the steady state component all were known as DC component.

So as DC component dies out rapidly, transient component it may last only for maybe four cycles after the inception of fault. So, the value of fault current also decreases with time. And moreover, we know that the protective device also take some time maybe one or one and a half cycle. So, wherever the breaker operation comes in picture it has to come only after one and half cycle after the inception of fault. So, whatever breaking capacity, we have to define that comes again after one and a half cycle after the inception of fault.

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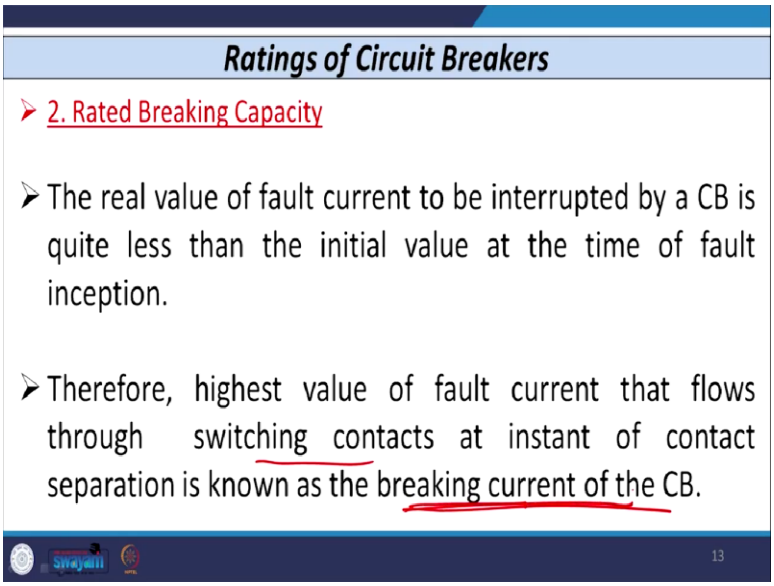

So, the real value of current that is to be interrupted by breaker that is lower than the actual value at the time of fault. So, therefore, the highest value of fault current that flows through the switching contacts or the contacts of the circuit breaker at the instant of contact separation that is known as the breaking current of Circuit Breaker.

So, breaking current of Circuit Breaker means what is the highest value or fault current that flows through the contact of Circuit Breaker at the time of breaking or contact separation that is nothing but the breaking current of Circuit Breaker. This current that is entirely different than the current that is exactly at the time of inception of fault, because after the inception of fault, that current that has to flow and relay has to take some time maybe one and a half cycle and then whatever current comes, that is the breaking current of the Circuit Breaker.

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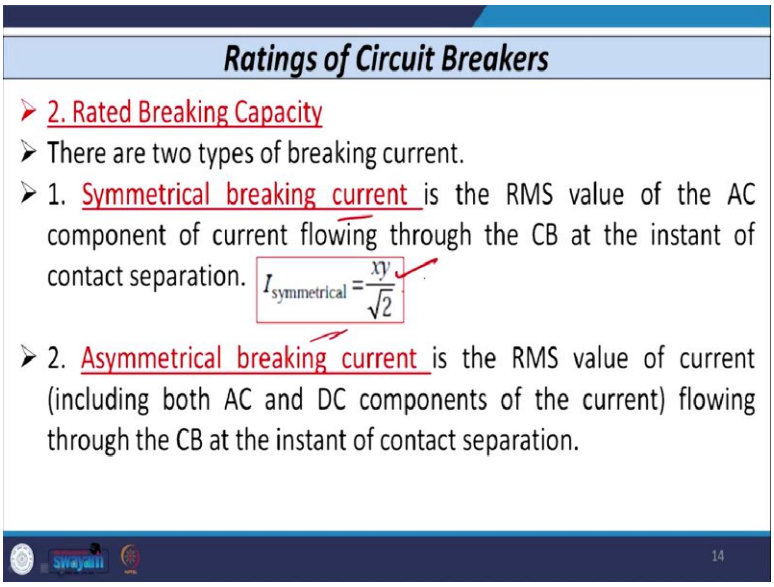

So, now the there are two types of breaking current: one is known as Symmetrical Breaking Current and the other is known is Asymmetrical Breaking Current. So, the Symmetrical Breaking Current that is defined as the RMS value of AC component of current that is flowing through the Circuit Breaker at the instant of contact separation. So, that is known as the Asymmetrical Breaking Current and it is defined by I symmetrical that is equal to some points on the graph divided by root 2.

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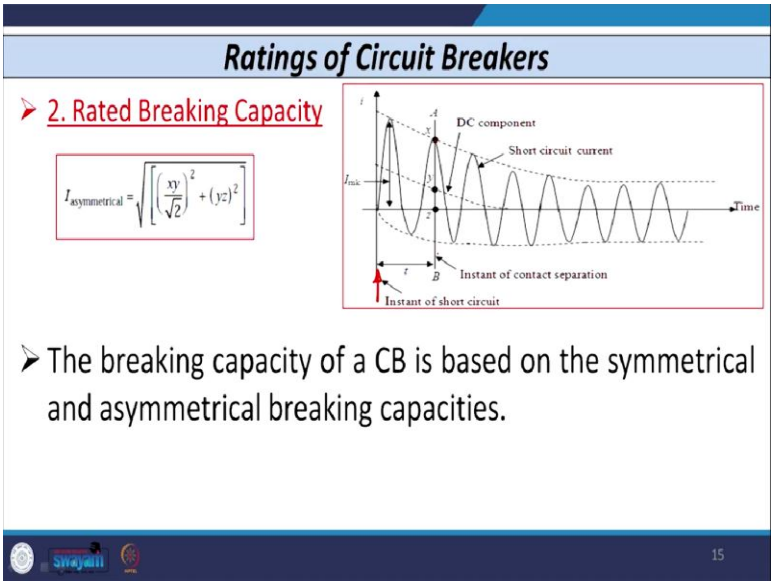

Now, if I just tell you this point, this X and Y, these 2 points are you can see there is a point X here. That is your X point and the other point that is the Y point here, that is this point. So, these two points if you take whatever is the current value magnitude that is known as the breaking current of the Circuit Breaker. Now, see the fault occurs at this instance, this is the instant of occurrence of fault. So, after that some time period t that is gone and after that whatever is the current that is known as the breaking current.

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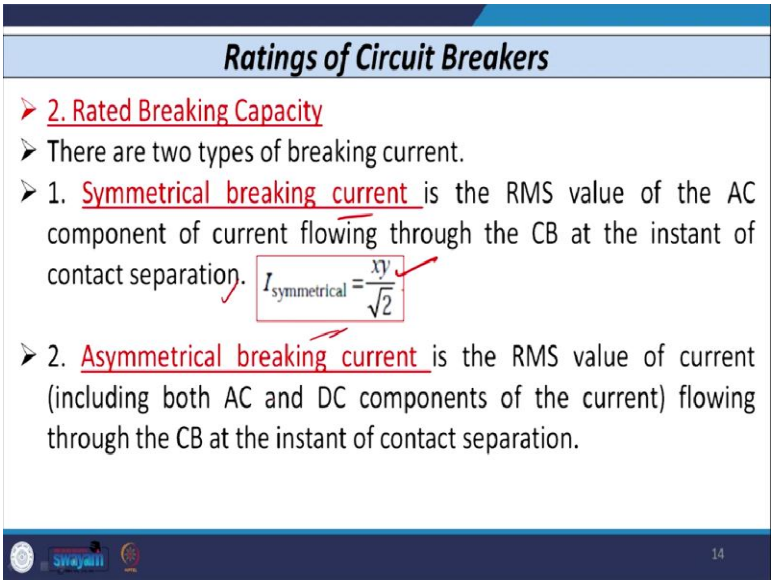

The other Asymmetrical Breaking Current that is defined as the RMS value of current that includes both AC and DC component of current that flows through the Circuit Breaker at the time of or at the instant of contact separation. So, symmetrical breaking current only AC current whereas the Asymmetrical Breaking Current that contains both AC and DC component.

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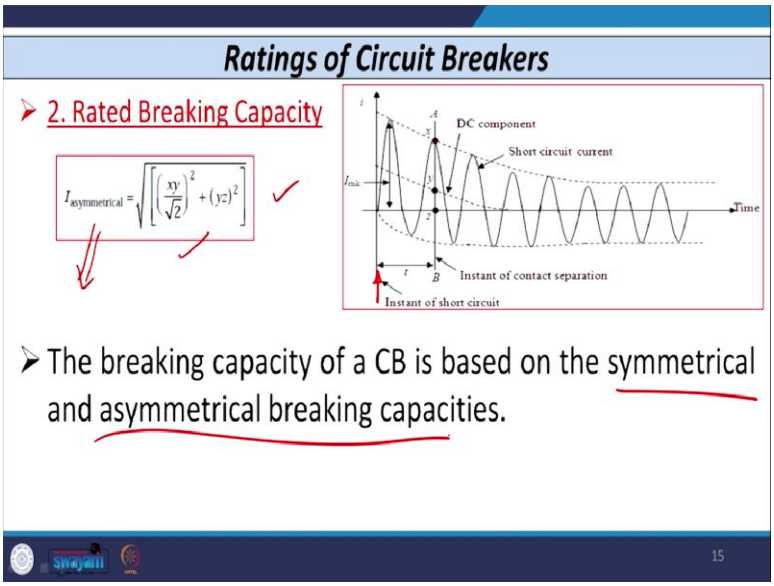

We can say that it is I asymmetrical breaking current that is defined as by this equation X Y by root 2 whole square plus Y Z whole square, so, X and Y points are here and Y is here and Z point is here. So, you can find out the Asymmetrical Breaking Current. So, the breaking capacity of Circuit Breaker that is based on the symmetrical as well as asymmetrical capacity of the Circuit Breaker.

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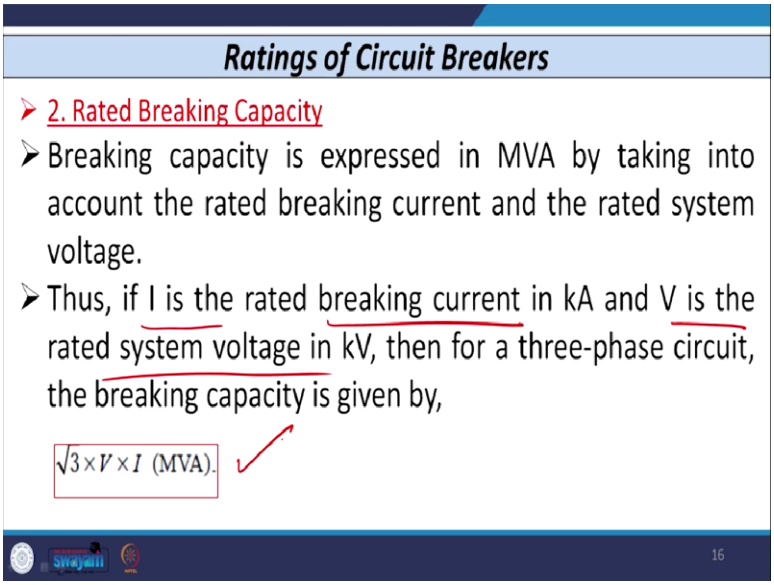

So, breaking capacity of the breaker that is usually expressed in MVA, so by taking into account the Rated Breaking Current and the Rated System Voltage, if you multiply these 2 with root 3 factor then you will get the value that is known as the breaking capacity of breaker and this value that is usually in MVA. So, if I consider is the Rated Breaking Current and that is in kilo ampere and V is the rated system voltage in kV then for three phase circuit the breaking capacity of the breaker that is given by the equation root 3 V into I and this value that is in MVA.

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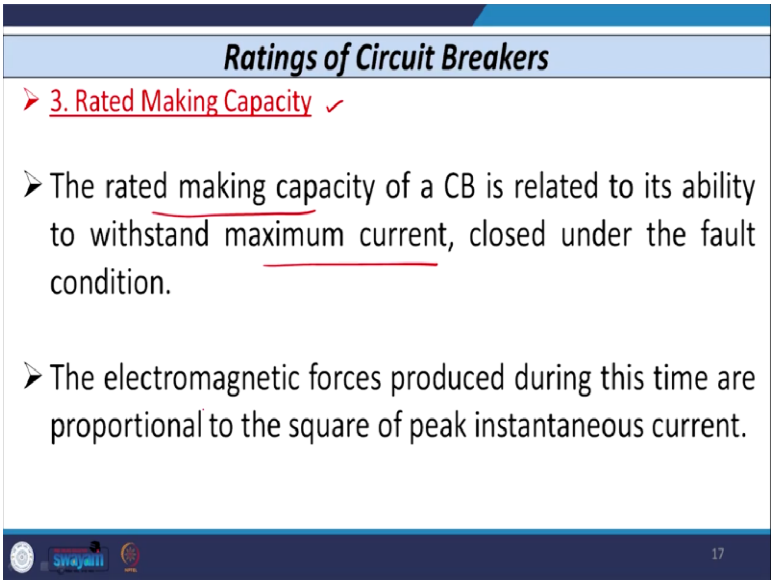

Now, let us discuss what is the Rated Making Capacity. Now as I told you breaking capacity of Circuit Breaker that comes or that is defined whenever the contact of the Circuit Breaker that becomes open or separate. The Making Capacity of Circuit Breaker comes in picture when the contact of the Circuit Breaker closes.

So, the Rated Making Capacity of Circuit Breaker that is related to the ability of the breaker to withstand maximum value of the current, this current that is greater than the symmetrical or as well as asymmetrical breaking current as we have defined in case of breaking capacity of the Circuit Breaker. So, we know that the electromagnetic force is produced at this time that are proportional to the square of the peak of the instantaneous current.

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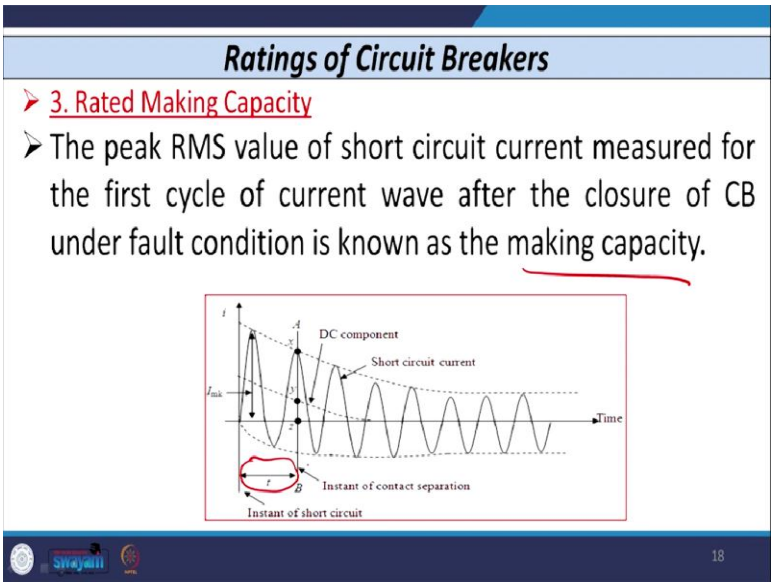

And so, the Rated Making Capacity that is nothing but the peak RMS value of short circuit current measured during the first cycle of the current wave that is the fault current wave, after the closure of Circuit Breaker under fault condition, so, this is known as the making capacity. So, in this time period t if I consider during this time period t, whatever value you consider that comes under the making capacity and after this point B, this after lapsation of time t whatever you consider that comes under the breaking capacity of the Circuit Breaker.

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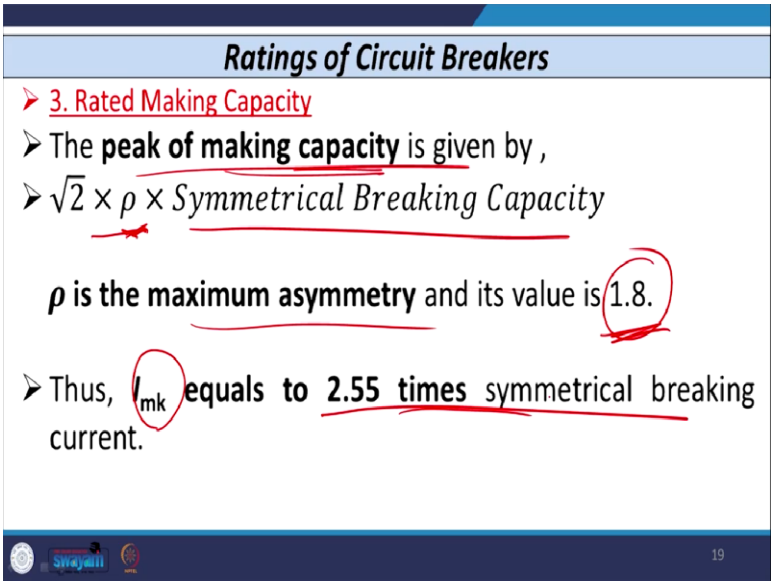

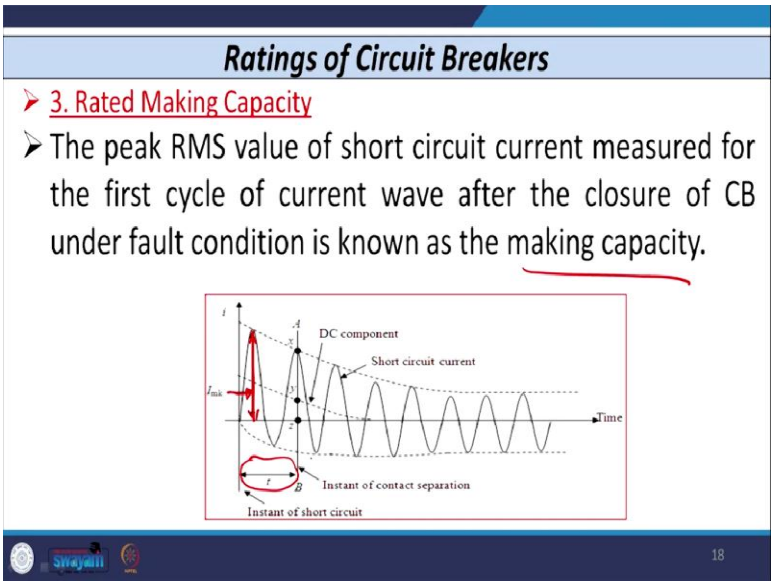

So, this peak of the making capacity that is given by the term root 2 that is the peak value with some constant into the symmetrical breaking capacity of the breaker. This we have already defined, where this constant that is the maximum asymmetry that exists in the fault current wave shape and its value that is usually 1.5 to 2. So, here I have considered 1.8.

Now, if I just wish to represent this making capacity or making current on the wave shape, then that is denoted by the current Imk So, you can see that this current I mk that is somewhere here, this current. So, whatever is the current here that is nothing but this value that is your, the I current I mk, and you can see this current that is in this time period t.

So, this value of Imk that is roughly 2.55 to 2.6 times, this Symmetrical Breaking Current. So, making capacity of Circuit Breaker is always greater than the breaking Capacity of Circuit Breaker, because making capacity that is defined immediately after the inception of fault maybe in one cycle, whereas the breaking capacity comes in picture maybe after two and a half cycle after the inception of fault.

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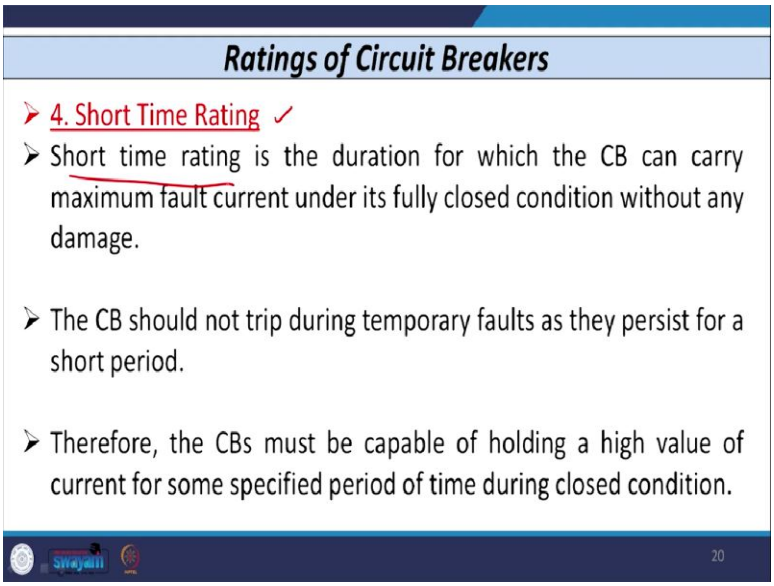

The fourth point that is known as the Short Time Rating of the Circuit Breaker. So, the Short Time Rating of the Circuit Breaker is nothing but the duration for which the breaker can carry the maximum fault current under fully closed condition without any damage or without any temperature rise. So, that is known as the Short Time Rating of the Circuit Breaker.

The breaker should not trip during temporary fault, because as they persist for a short period only. So, the Circuit Breaker must be capable of holding a high value of current for some specified or prescribed period of time during close condition. So, this is all about the short time rating you have to define the time up to which the breaker is capable to withstand the short circuit current that is nothing but in short time rating or short time duration of the circuit breaker.

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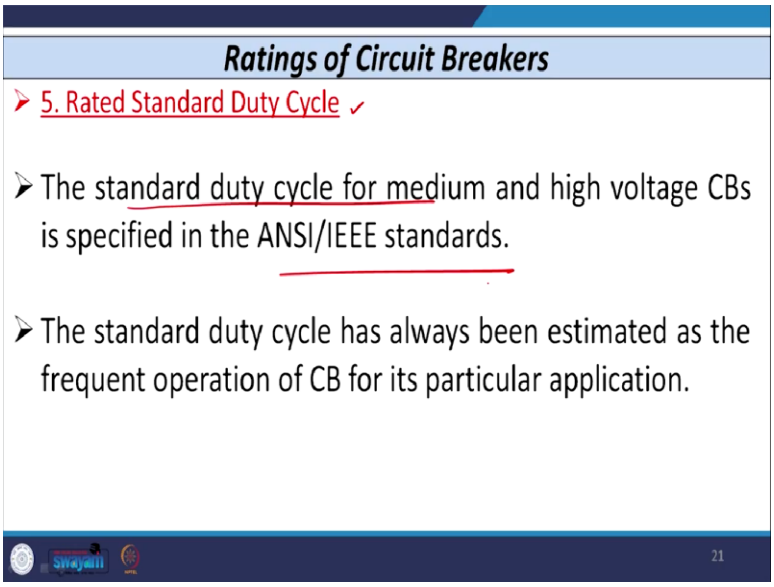

The fifth one that is known as the Rated Standard Duty Cycle of the Circuit Breaker. So, the standard duty cycle of the circuit breaker may be for medium or high voltage circuit breaker that is specified by IEEE or ANSI standards. And this standard duty cycle has always estimated based on the maybe what type of function they need to perform by the breaker.

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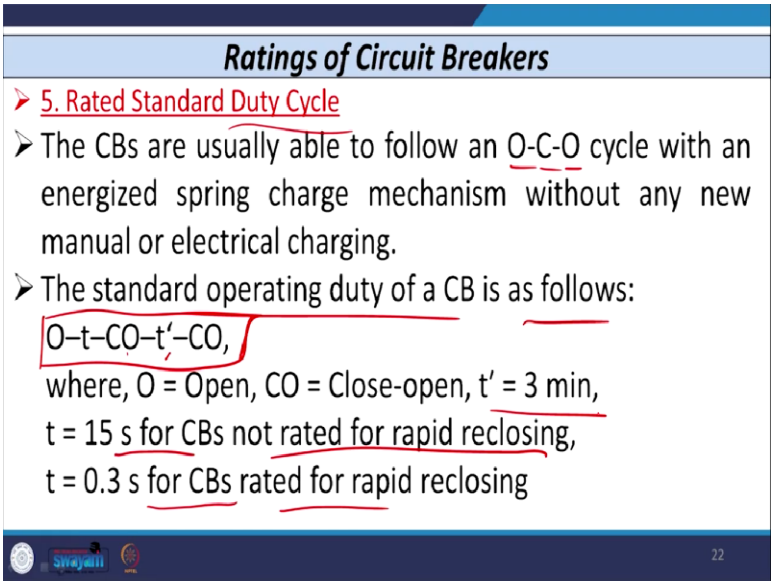

So, if I just want to define, this Standard Duty Cycle, then this breaker that should allow the opening closing and opening operation of the cycle within certain period of time. So, if I just want to define the standard operating duty of the Circuit Breaker then that is given by this equation.

Now, you can see in this equation O that indicates the opening of the breaker, then t that is nothing but the, some time constant, maybe 15 seconds for Circuit Breaker not meant for rapid reclosing and 0.3 seconds for the breaker designed for the rapid reclosing. The CO that is known as the closing followed by opening operation and then again, you have the t dash that is the time constant for 3 minutes and again then you have the closing followed by opening operation. So, this is nothing but the standard duty cycle of the circuit breaker.

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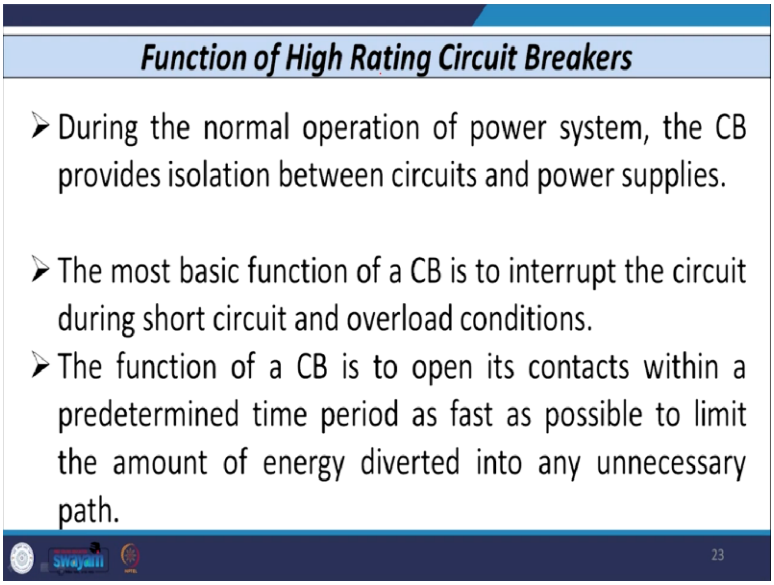

So, this is all about the there are certain standard terms or fundamentals related to the Circuit Breaker and the 2 terms are very important one is breaking capacity and another is making capacity of the Circuit Breaker. Of course, we have also defined the, some duty cycle of the breaker as well as the what is the rated current rated voltage of the breaker as well as we have also discussed, what is this short time rating of the breaker. So, this also we have discussed.

Now, before that, we started our discussion with the whenever the Circuit Breaker that is interrupted the capacitive current or small value of capacitive current then very high voltage that

is going to induce across the contact of Circuit Breaker and that voltage must withstand by the breaker and if I want to reduce it then we have to connect the, we have to use the resistance switching technique that also we have discussed. So, I stop here and we will continue further in the next class. Thank you.