Power System Analysis
Prof. A.K. Sinha
Department of Electrical Engineering
Indian Institute of Technology Kharagpur

Lecture - 25
Short Circuit Analysis

Welcome to lesson 25 on Power System Analysis. In this lesson, we will learn about Short Circuit Analysis and Power Systems.

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The lesson will start with an introduction to short circuit analysis. Then, we will discuss about the causes and consequences of short circuit. Then, we will go into the different types of short circuit is or faults, which occur in power system. And finally, we will discuss about, how to do short circuit analysis, for a symmetrical system, basically for symmetrical faults.

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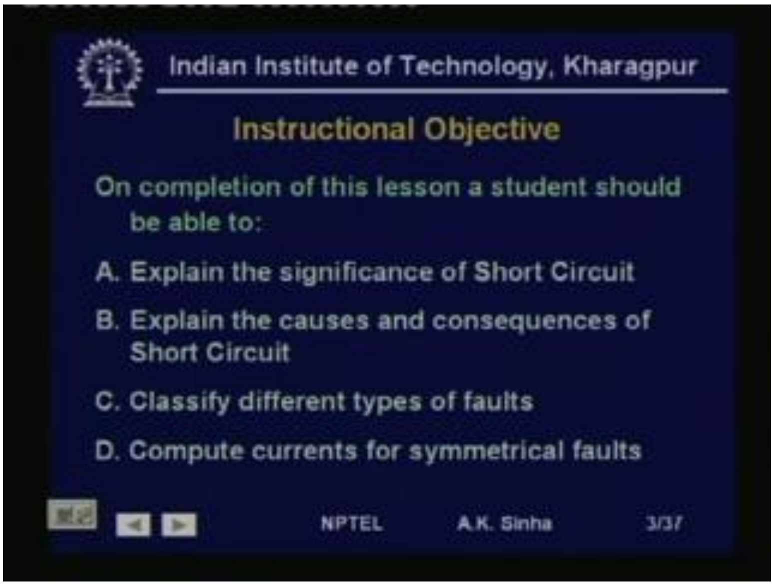

On completion of this lesson, you should be able to explain the significance of short circuit. You should also be able to explain the causes and consequences of short circuit. You should be able to classify different types of faults. And you should be able to compute currents for symmetric al faults.

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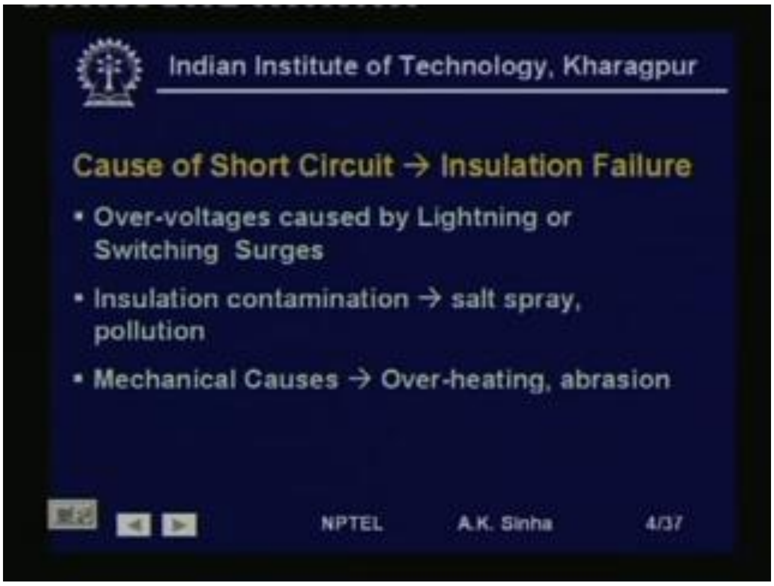

Well, short circuit is are not very common in power system. But, they do occur and one of the major causes or consequences of short circuit is very heavy currents, because short circuit is create or reduce the impedance of the system. Considerably, thereby increasing the current flowing through the components and the consequences of these heavy currents on the system is very disastrous.

If they are allowed to stay for a longer time and therefore, the short circuit is need to be isolated as quickly as possible from the system. This is done by means of protection systems and the switch gears the relays in the protection system. Basically, will try to find out, whether as there is a fault in a circuit, in case it finds it, there is a fault, it sense a signal to the circuit breakers to isolate the fault by opening the circuit.

This needs to be done very fast. In case of high voltage systems, this is normally done in less than 3 to 5 cycles. That is, in the time frame of around 60 to 100 milliseconds. Now, let us take up, what causes short circuit is. Well, short circuit is are caused, mainly because of insulation failure. Whenever, insulation fails, we have a short circuit in the system.

Now, what are the reasons, which create this insulation failure? Well, one of the reasons are which is very much prevalent is over voltages, which are caused by lightening or switching surges. So, lightening strikes a transmission line, so there is travelling wave high voltages are created, which can puncture the insulation. Or can bridge in certain cases, the air insulation between two conductors and thereby causing short circuit.

The other reasons for short circuit are insulation contamination. That is, it happens especially in regions, where there is high pollution or if the transmission line or equipment or near to the seashore. There can be salt sprays created are because of the wind blowing. So, these salt sprays, basically create a film of conducting material on top of the insulating surfaces or the insulators on overhead transmission line.

Pollution also does a similar kind of a thing. That is, it creates a conducting surface on top of the insulators, which are the support for the transmission line from the towers. And thereby, making the insulator fail and causing short circuit is. The other reasons can be mechanical causes, which are basically overheating or abrasion. Overheating, if we allow our equipment to be overloaded for a longer time, then what happens is the insulation deteriorates.

Because, of the high temperature in the system. And this deterioration, over a long period of time, may lead to failure. Because, of the vibrations, which take place in the machines or by the cycle of contraction and expansion due to heating and cooling in the equipments. Similarly, abrasion can also cause a failure of insulation and thereby, lead to short circuits.

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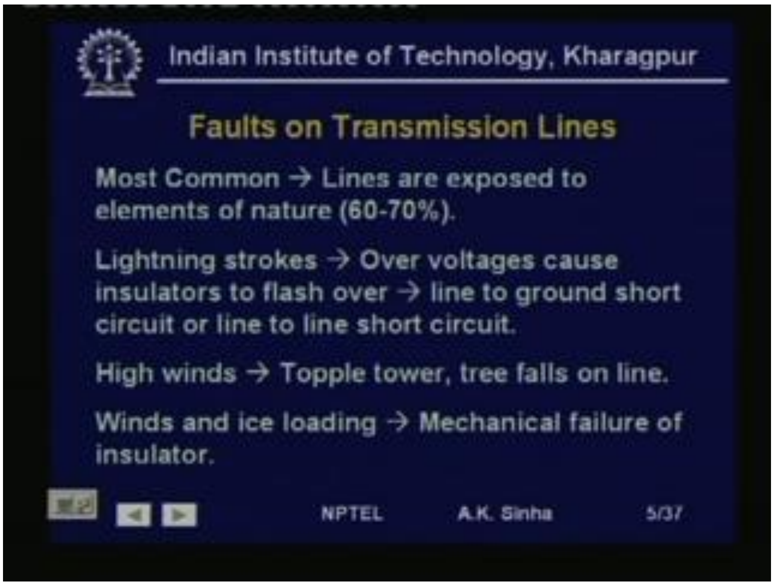

Faults on transmission lines, these are the most common faults. One of the reasons is, transmission lines are mostly overhead lines. And these lines are exposed to elements of nature, these are outside. And they are exposed to lightning, they are exposed to high winds, they are exposed to storms, they are exposed to rains. All kinds of elements of nature and therefore, they are more prone to short circuit is or faults.

Statistically, it has been found that almost 60 to 70 percent of the faults or on overhead transmission lines. The reasons for this faults as I said earlier, are lightning strokes, lightning strikes a transmission line over voltages are created. Because of the travelling waves, which travel on the transmission line in both the direction. And when they come near the tower or the insulators, they can create a flash over from the insulator to the tower or between two lines. This can concrete a line to ground short circuit or a line to line short circuit.

Well, again high winds, can topple the towers and thereby, creating a short circuit. Because, all the lines will be falling on the ground and this will cause short circuit is between line and the ground and may be even two lines or 3 lines together. Trees can fall on the transmission lines and thereby, short circuiting them. So, this is another cause, which happens in fact, trees have been found to be a major cause of many falls.

One of reasons, which this happens is, many times trees are there below the transmission lines. And if they are not trimmed regularly and sometimes, when transmission lines are carrying heavy currents or they are overloaded. Because, of the heating the sag of the line increases and thereby, the lines can touch the tree. And if there is a rain or some such things occurring at the same time, the short circuit does occur. And thereby, creating short circuit, between the line and the ground or may be even two lines.

Sometimes, this wind and ice loading can also create falls. Because, the ice coated on the transmission lines increases it is weight and thereby, increasing it is sag. And sometimes, can break the line near the insulators or can cause the failure mechanical failure of the insulators.

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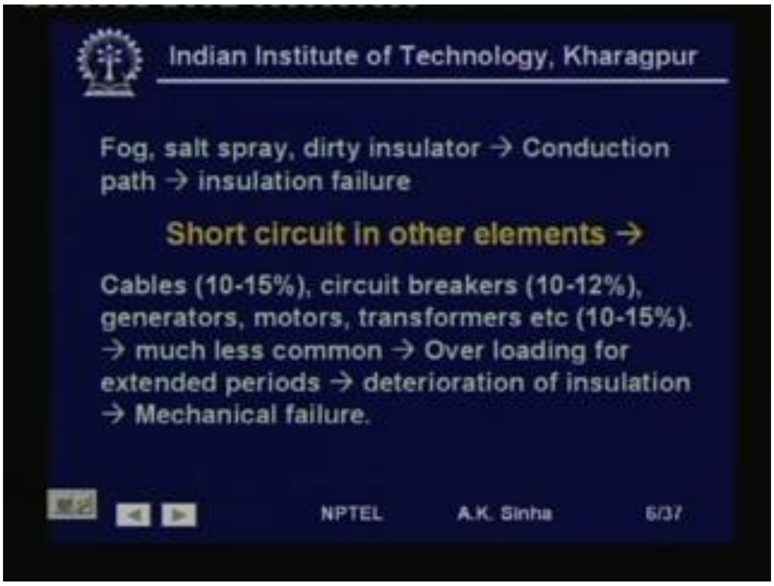

Pollution like fog salt spray, dirty insulator, also leads to short circuit. Because, these create a conducting path, over the insulation surface and thereby, the high voltage of the line and the tower, which is grounded, they get a conducting path. And thereby, arc gets established between them and this causes the short circuit or an arching fault. Short circuits also occur in other elements.

Cables, they are underground and the faults on them are somewhat rare. Mainly, because they are not exposed to the element and the falls, occur mostly, because of either some mechanical damage to the cable. If there is some digging going on nearby or overloading of the cable, ruptures it is insulation or over a period of time. It is insulation deteriorates and causing short circuit.

Circuit breakers also can have short circuits and these are again much less common. But, they do occur on circuit breakers. Generators motors and transformers, they also can have short circuits in these elements. That is in generators, motors and transformers, also can be short circuited or do get short circuited, once in a while when they are overloaded. Though, the statistically the number of falls on these equipment is much less compared to that on the transmission lines themselves.

Therefore, these falls are much less common. Overloading for extended period is the main reason for faults on these equipments. Because, this overloading over extended period, causes the deterioration of the insulation and this leads to mechanical failure of the insulation. Because of the vibrations in the machines or because of the cyclic heating and cooling, heating, during heavy load conditions and cooling during light load conditions. That creates a mechanical failure in the insulation which has already deteriorated.

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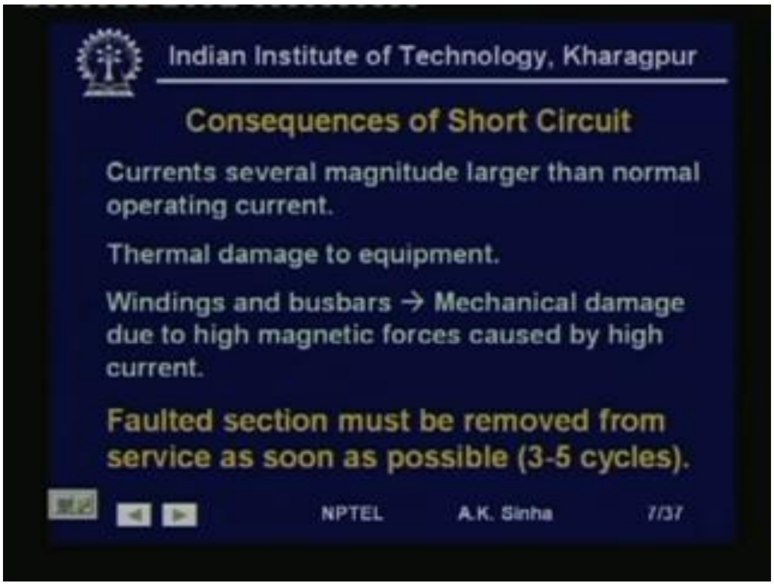

Now, what are the consequences of short circuit? Well, as we said when insulation fails. We get a conducting part, between the high voltage and a ground or between two high voltage conductors. And this insulation is being or this conducting path having very low impedance. The currents of several magnitudes larger than the normal operating currents can occur during short circuits.

Well, what happens due to this current, very well, when this heavy current is flowing? The one effect that we all understand will happen is the thermal damage to the equipment, because this current is going to create a very high temperature in the equipment. If the current is say 5 times, the normal operating current, then the heating produced, will be proportional to I square.

And therefore, it will be 25 times, thereby causing very high temperatures, which may lead to even burning of the insulation and fire in the equipment many times. The other reason is, especially on windings and busbars. Because, of this heavy currents, mechanical damage can also occur, because heavy magnetic forces will be produced between the windings of the coil and the busbar conductors.

Therefore, faulted section must be removed from service as soon as possible. As I said earlier this on EHV system or high voltage system is done, within 3 to 5 cycles. That is within 60 to 100 milliseconds for a 50 hertz system.

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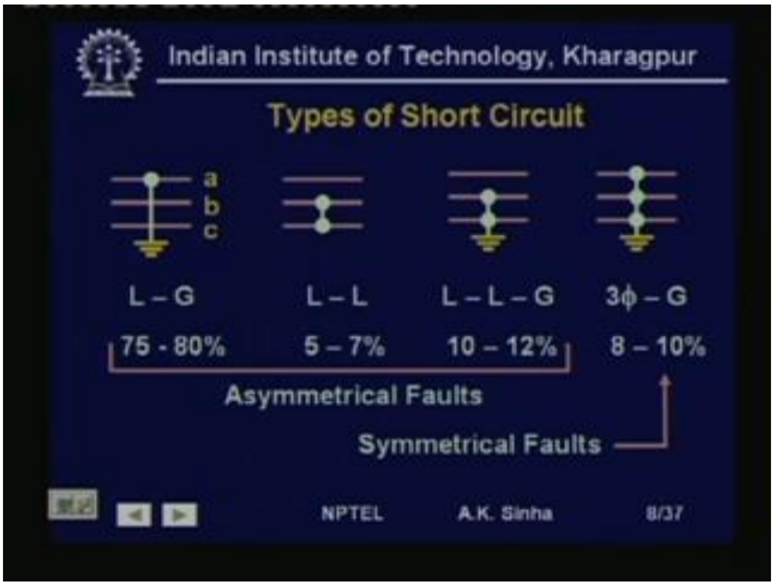

Now, we will discuss about, what are the various kinds of short circuits, which can occur. Well, the simplest one, as we see here is a single line or phase A of the conductor is grounded. That is, there is a short circuit, which occurs between one conductor and the ground. This we call as a line to ground fault and almost 75 to 80 percent of the faults are of this type.

Another type of fault can be, when insulation fails between two conductors. Then, we have a fault between or a short circuit between two conductors. Here, it shows a short circuit between phase b and c. This can be between a and b or between a or c, as well.

This type of fault, we call as line to line fault or L L fault, around 5 to 7 percent of the faults are of this nature.

This is much less common, because especially in cases of overhead lines are even cables or other equipment. The windings or the conductors between two phases are much further away from each other and chances of a line to line fault is much less. Then, other kind of fault is the two lines are shorted and this gets shorted to the ground, which we call as double line to ground fault or LLG fault. Line to line to ground fault, around 10 to 12 percent of the faults are of this type. Mostly, when we have a line to line fault, many times this also becomes a line to line to ground fault, because one of the conductors, gets faulted to the ground, as well.

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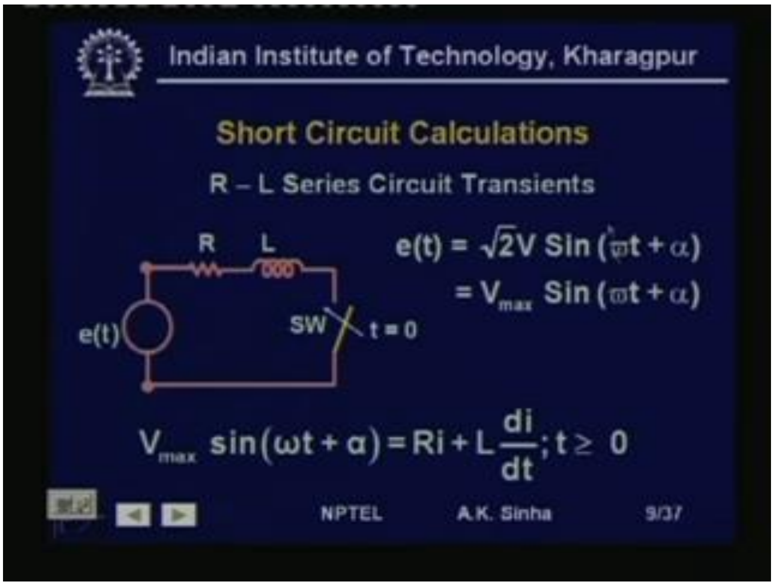

The other kind of fault is, when all the three phase are faulted or shorted or the three phases are shorted to ground. So, we have either a three phase short circuit or a three phase to ground short circuit. Now, this around 8 to 10 percent of the faults, are of this kind. This is only some indication of which has been shown here, from the statistics from various countries.

Now, if we look at the type of faults, we find this line to ground fault. If we have, then what we find is, in this there is going to be a heavy current flowing in phase a. Whereas, phase b and c, will not be experiencing heavy current, because they are not faulted or they are not connected or shorted to ground. So, what we find is the current relationships, as well as voltage relationships on the three phases. In case of this fault is not going to be same. So, this kind of fault is an asymmetrical fault.

Because, if you see here, phase a is to ground, which means the voltage of phase a, at this point becomes 0. Whereas, the voltage of this b and c are not going to be affected that much, there will be still a high value, may be somewhat lower than the normal value. So, the voltage relationship for the three phases are not same. Similarly the currents in the three phases are not same. So, this is a symmetrical situation, that is the currents and voltages are not symmetrical balanced in this case.

Now, here, we find a line to line fault. Again, here phase a is not affected. So, there is not going to be much current in that phase. Whereas, phase b and c are shorted. So, they will be carrying heavy currents. This situation is again unbalanced situation, where b and c the voltages will be same at this point. Whereas, the phase a voltage will be very near to the normal voltage. Whereas, these voltages are going to be much lower as well as these phases will be carrying much heavier current.

Again, double line to ground fault, same situation b and c, the voltage will be, ground voltage, that is 0. And the current flowing in them will be much higher, whereas phase a is not ((Refer Time: 20:17)). Affected, it is voltage will be very near to the normal, may be lower, somewhat lower than that and it will not be carrying that heavy current. So, this again is a symmetrical fault. So, line to ground fault, line to line fault or line to line to line ground faults are a symmetrical or unbalanced faults.

That is, when these faults occur or these short circuits occur, the system voltage and currents are unbalanced. Whereas, when we have a three phase fault or a three phase to ground fault, in that case all the three phase will be experiencing the same condition. And therefore, the current and voltage in all the three phases are going to be same. This condition is a condition for symmetrical voltage and currents. Therefore, three phase to ground fault are three phase fault is asymmetrical fault.

Now, if when we have a symmetrical fault, then since all the currents and voltages in all the three phases are going to be of the same nature. In the sense, that they are balanced having the same magnitude and 120 degree out of phase from each other. Therefore, as we have seen earlier, we can still use a single phase analysis for this. Because, if we do the analysis for one phase.

The same currents and voltages will be in the other phase, say we do it for phase a. Then, b and c, will have the same currents and voltages, except that, they will be 120 degree out of phase, from the current and voltage of phase of a.

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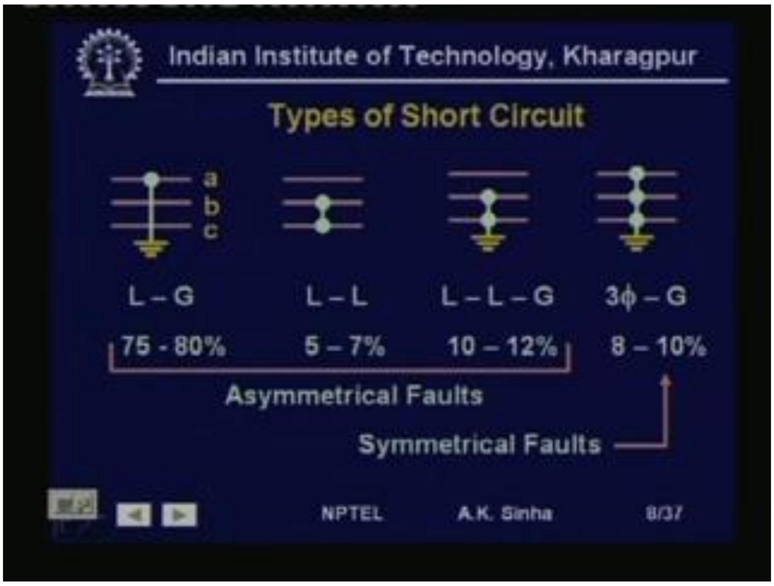

So, therefore, we will look into the symmetrical faults, first because this analysis is much simpler. Whereas, in case of symmetrical faults, this is a condition for unbalanced and we have to do the analysis for unbalanced system, we will talk about this later. How, we tackle the unbalance system operation and analysis. Before, we start with the short circuit analysis in a power system; we will just review briefly the short circuit.

Condition for a circuit, which is excited by and an ac voltage e t, where e t is root 2 V sin omega t plus alpha and the circuit has a resistance and inductance. This is what we are going to experience in most of the power system, where the element impedances are going to be resistance and inductance, mostly and the voltage is a sinusoidal voltage. So, this is a single phase part, that we are taking, we can do this analysis for three phase as well.

Since, we are talking about symmetrical short circuit is right now. So, if we do the analysis for one phase, it is valid for the other two phases as well. And therefore, this voltage that we will be choosing, in this case, will be a line to neutral voltage for the system. So, again looking at this, we have for this circuit, when we close this switch at time t is equal to 0. Then, we have the voltage here V max sin omega t plus alpha is equal to R i.

If the current i is flowing in this circuit as when we close this switch. Then, it will be R i plus L d i by d t for t greater than equal to 0. So, after closing the switch, this is the relationship, which gives us the voltage current, relation for the circuit, for all times t greater than 0.

Now, solving for i t from this equation, we will get i t is equal to V max by Z into sin omega t plus alpha minus theta, minus e to the power minus R t by L into sin alpha minus theta. This is the solution that we get for this equation. This is the first order differential equation. So, when we solve this for i t, we will get this as i t, where Z, magnitude of the impedance, which will be equal to R square plus omega L square.

That is the impedance, if we look as a phaser or as a vector; Z is equal to R plus J omega L, where omega L is also written as reactance X. So, Z magnitude is equal square root of R square plus omega L square. And theta is the impedance angle and is equal to tan inverse omega L by R per tan inverse.

Now, for this, we can write from this equation, i t has two parts. One is this part, where it is sin omega t plus alpha minus theta. This part is a sinusoidal wave form, which will be coming. Whereas, this part is a part with the current is decaying slowly with time and it is not a sinusoidal component. So, we have two parts of this current. That is i t is equal to i a c t, where the sinusoidal part is a c part, with wit h the frequency omega, angular frequency omega.

And this is the d c part, which is decaying from a given value or a maximum value 2 0 as time increases. So, we have i a c t plus i d c t as the current i t. Now, i a c t is the symmetrical fault current and remains constant. In the sense, that it is magnitude is constant and the frequency is constant, i d c t is called the d c offset current and this decays with time. This is what we said, this is shown from here e to the power minus R t by L.

So, as t keeps on increasing this value is will keep on decreasing the maximum value at t is equal to 0 is going to be V max by Z. So, here D C offset current is i d c t and i t is the total current which is a asymmetrical fault current, it is not a symmetrical A C current.

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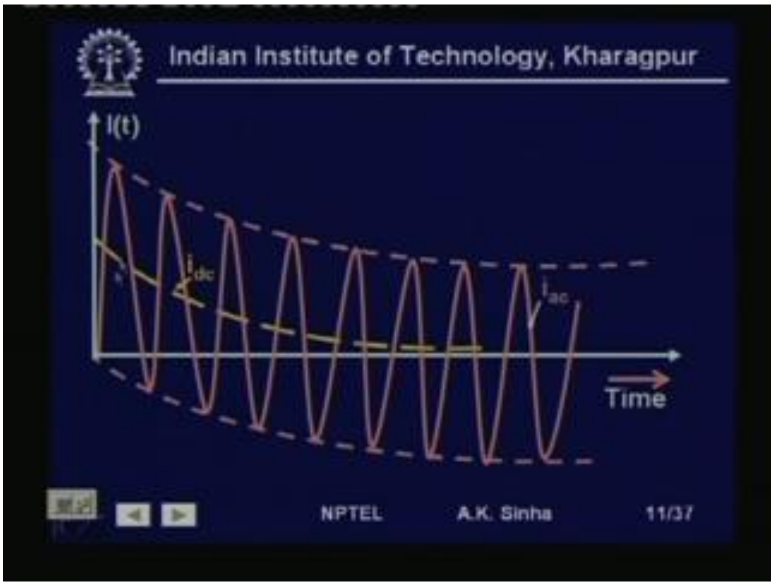

This can be seen from this diagram, this is the A C current, which is their sinusoidal A C current and this is the D C offset current. And therefore, the wave form, if you see comes out looks like this; it is not symmetrical about the x axis, which is the time axis. But, as time increases and goes to at infinity, i d c is becoming 0 and then it becomes symmetrical about the x axis. So, this is the kind of current that we would see in case of a short circuit on a R L circuit.

Now, the system in power systems is very similar to this. If we take a synchronous machine, it has a winding, which is leakage reactance and it has also some reactance to take care of the armature reaction. And it has a winding resistance, all these put together we call this as a synchronous impedance. So, it has a resistances and reactance or inductance in series.

If we take a short circuit profile on a synchronous machine; however, we find that the profile is not like this, but it is somewhat different. Like, if we take a three phase short circuit on a synchronous machine the profile of the current will appear like this. Initially the current magnitude is going to be much higher. Now, mind it, here we have neglected the D C current or the DC offset current.

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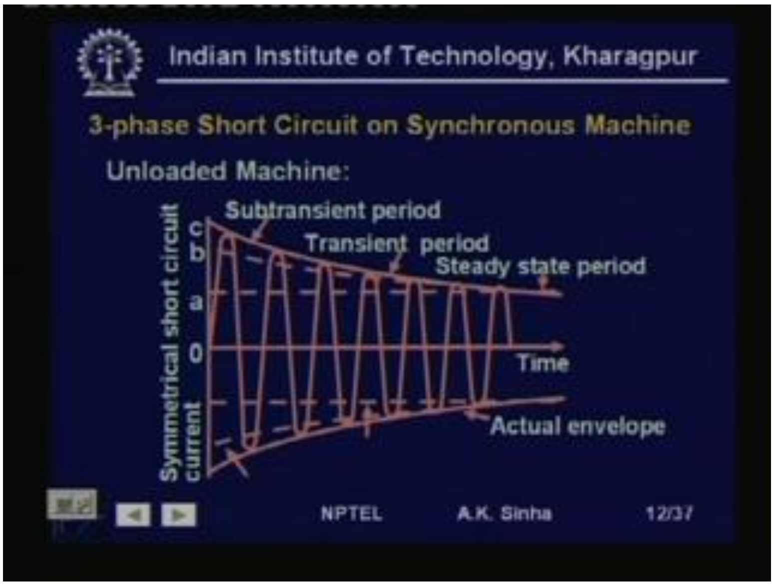

If we take the D C offset current, also then that needs to be added to it. So, this whole profile will shift further on this side. So, it will become more a symmetrical. But, even if we do not take the D C offset current, we find that initial current values are much larger and later, it keeps on decaying. And finally, we get a steady state value. Now, why does this happen, we have discussed in synchronous machine model, that the machine does not show constant impedance.

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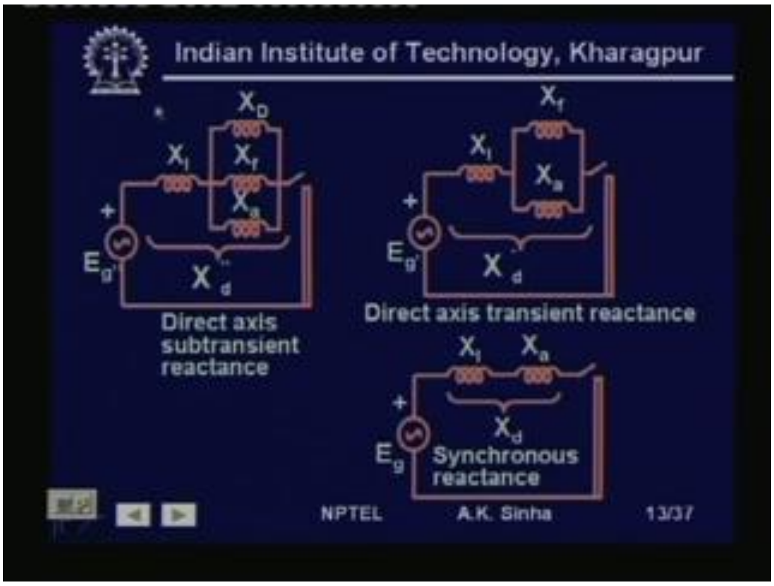

But at that time of short circuit, it shows much lower impedance. Why, because we have either the leakage impedance or the leakage reactance part of the winding. Plus the armature reaction part X a, the field winding reactance and X D. The damper winding reactance, all these 3 are in parallel and thereby, reducing the total reactance of the machine to a much lower value, which we call as the direct axis, sub transient reactance. Whereas, after some time the damper winding current, die out that this happens within two cycles or so 2 to 3 cycles.

So, in the after that, this reactance is no longer effective, because no current is flowing through it, this becomes an open circuit. So, we have only X f and X a in parallel and then we have this reactance, which is effective and this reactance, we call as the direct axis transient reactance. And this is therefore 5 to 8 or 10 cycles. After, which again the field current, that is the transient current in the field is has decayed and we have this as an open circuit.

And therefore, we have only X l and X a, which we call as the direct axis synchronous reactance of the machine. So, we find that, the synchronous machine shows different reactance’s at different point of time, after a short circuit. Initially, just after the short circuit, we see the sub transient reactance, which is much smaller. Then, we see after if 2 to 3 cycles, we see the transient reactance, which is somewhat more than sub transient.

And after 8 to 10 cycles, we see the reactance, which remains more or less constant and that is the synchronous reactance. So, if we go back on this diagram, then we can see that O c, this O c is giving us the sub transient current. Whereas, O b which is an extension of the transient period. Here, is giving us the transient current and O a, which is the steady state current value is giving us the steady state current or the current, due to synchronous reactance of the machine.

So, therefore, with the synchronous machine, we normally since we will be interested in the maximum current, which flows through the machine, most of time, while doing this short circuit analysis, we consider the sub transient reactance only. If we are considering periods a little after the sub transient period, that is during the transient period. Then, we consider the transient reactance. But, generally finding out the short circuit currents we are more interested in finding out what is the maximum value of the short circuit current. We would be using in that case sub transient reactance only.

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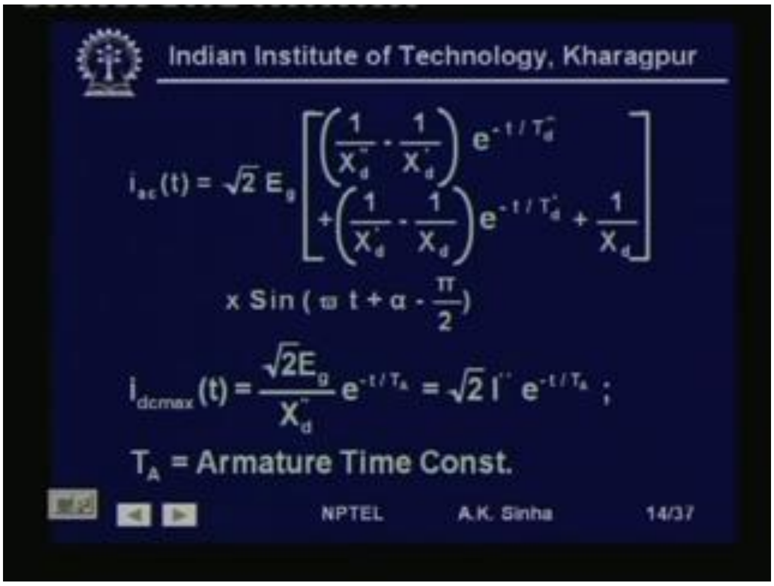

So, in this case if we see again, considering the D C current to be 0, the A C's current is not symmetrical as such. Because, it has a decaying term, depending on the sub transient direct axis sub transient time constant depending on the direct axis transient time constant and so on. This is current is given as i a c at time t is equal to root 2 times E g into 1 divided by X d double dash.

This is a sub transient react, direct axis sub transient reactance minus 1 by X d dash, direct axis transient reactance into e to the power minus t by Td dash or this is tau T dash. That is the direct axis sub transient time constant plus 1 by X d dash minus 1 by X d into e to the power minus t by T d tau d dash, where tau d dash is the direct axis transient time constant plus 1 by X d.

So, this is the current into sin omega t plus alpha minus pi by 2. So, this is what is showing as this current, this current is shown by this equation. Now, if we take the d c current also. Then, the maximum d c current, which depends again on time is equal to root 2 times E g by X t double dash e to the power minus t by tau a, where tau a is the armature time constant, which is same as root 2 times i double dash, where, i double dash is what? i double dash is the sub transient current into e to the power minus t by tau a.

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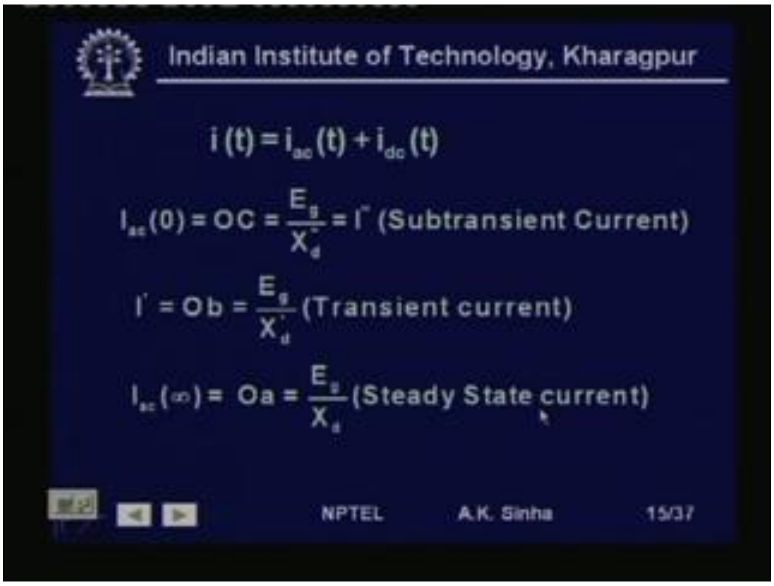

I t is going to be equal to i a c t plus i d c t. That is the a c current plus the d c offset current and this current at time t is equal to 0 is i a c at time t is equal to 0 a c is equal to O C, which we said is i double dash or the sub transient current is E g by X t double dash i dash, which is equal to O b. That is the transient current is equal to E g by X d dash. And i a c infinity, this should be I ac dash i a c infinity is equal to O a, which is equal to E g by X d. This is the steady state short circuit current on the same transmission.

This is what happens, if we do the short circuit at the terminals of the synchronous machine, when it is operating in the normal mode. That is operating at normal voltage, but it is unloaded.

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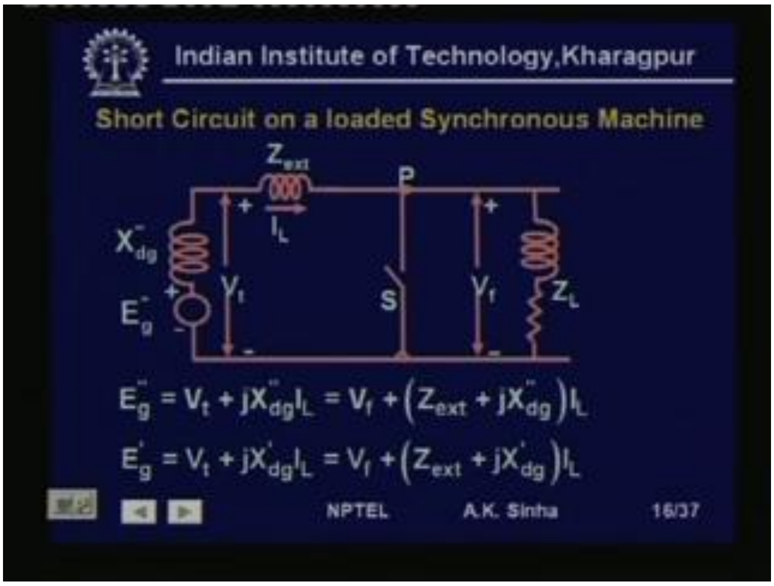

In case, the machine is loaded, then there will be current flowing through this and since machines adjust it is excitation current to keep the terminal voltage constant. That is, this voltage at the terminal v t as constant. So, we need to find out the internal voltage in this case, which is not going to be equal to E g. In case of unloaded machine, E g is equal to the nominal or the terminal voltage V t, because no current is flowing.

But, when the machine is loaded, then there is going to be a drop. Because, of the external circuit reactance or the impedance, that is the generator is connected through a transformer and transmission line to the load. Therefore, this Z x terminal is showing, that reactance X dg double dash is the direct axis sub transient reactance of the machine. So, we need to find out E g double dash, which is going to be equal to V t plus J, X d g double dash into I l, where we have V t here, the terminal voltage.

Now, if we see, if we are going to create a fault at the load point, then we have the voltage V f the fault voltage here. This will be, this E g double dash is going to be equal to V f, this voltage plus the drop, which takes place in this, which is Z external plus j X d g double dash into I L. Same thing, in case we are using the transient reactances, then we need to find E g dash and we will write this as V t is equal to E g dash is equal to V t plus j, X d g dash into I L. This is equal to V l plus Z external plus j, X d g dash into I L.

So, this is just to take care of the drop, due to the external impedance and the sub transient reactance or the transient reactance of the machine. So, we need to compute this E g dash or E g double dash in this case.

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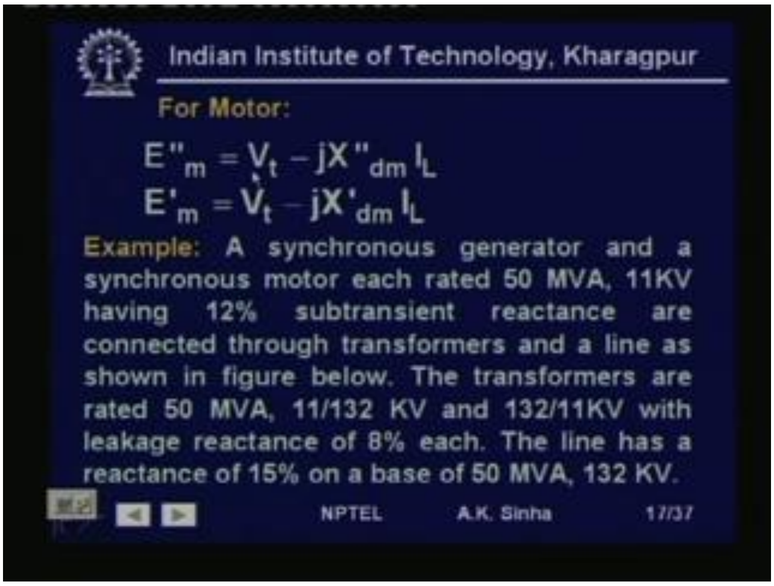

Similarly, if it is a motor, then we need to subtract this drop from the terminal voltage to get the internal voltage of the motor. That can be sub transient or transient volt internal voltage of the motor. Now, let us take a simple example to illustrate, how we can calculate the short circuit current for a small system. So, in this example, we have a synchronous generator and a synchronous motor each rated at 50 MVA, a 11 KV having 12 percent sub transient reactance.

Now, 12 percent sub transient reactance means 0.12 per unit reactance are connected through a transformer and a line as shown in figure below. The transformers are rated at 50 MVA a 11 is to 132 KV and 132 is to a 11 K v with leakage reactance of 8 percent each. So, again the transformer reactance is 0.08 per unit and all these are given on the same MVA and the voltage base values.

Therefore, we do not need to convert them, but if these reactances are given at different base values. Then, we will have to choose one base for the system and convert all these impedances or reactances to that base. This is what we had learnt earlier, when we discussed about per unit system.

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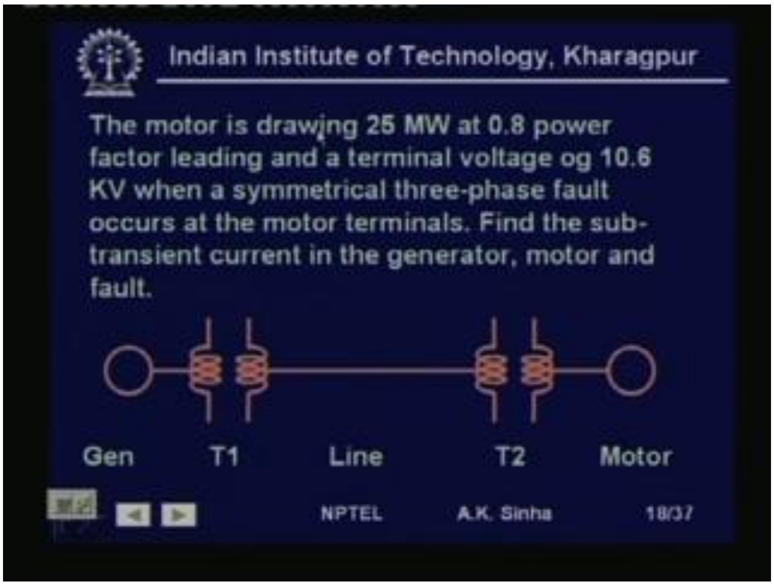

The line has a reactance of 15 percent and a base of 50 MVA and 132 KV. The motor is drawing 25 Mega Watt at 0.8 power factor leading. Now, this is the synchronous machine. So, by overexciting it, we are taking a leading current and a terminal voltage of this should be half 10.6 KV. So, the terminal voltage here is 10.6 KV, the nominal voltage given is 11 KV, when a symmetrical three phase short circuit occurs at the motor terminals. So, here a symmetrical three phase short circuit occurs, find the sub transient current in the generator motor and fault, this is the problems. So, a fault has occurred at this point, now we need to find out the sub transient current from the generator, from the motor, as well as into the fault.

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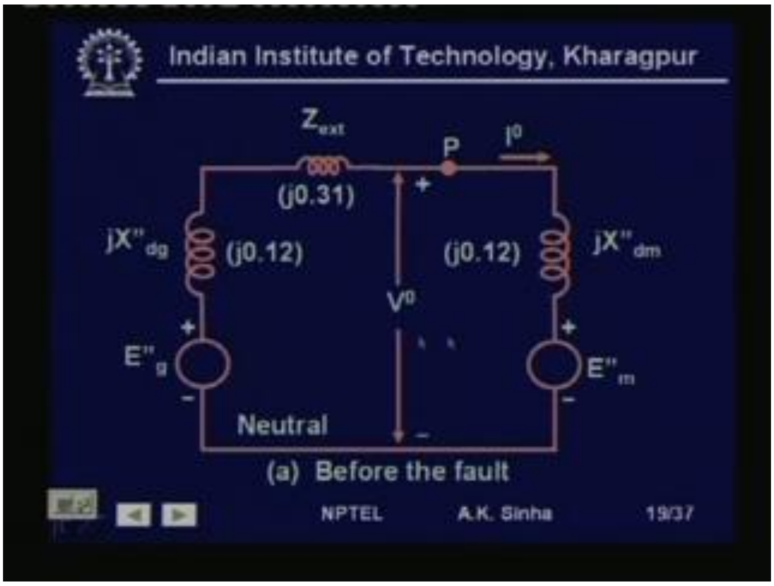

So, let us make the diagram, circuit diagram for this circuit. Then, we have E g double dash, the internal voltage of the generator, X d g double dash, the sub transient reactance which is 0.12 per unit. Now, external reactance is coming from, this is 0.08, this is 0.08 and this is 0.15. So, total comes out to be 0.31, so 0.08, 0.08 plus 0.15, 0.31. We have the internal voltage of the motor and the sub transient reactance of the synchronous motor as J 0.12. That is 12 percent and the fault has occurred at this point P. So, first thing that we need to do is, need to find out, what is the voltage before the fault, at this point. This is what we call the before fault voltage V 0. Now, this is already given in the problem as 10.6 KV, we will have to convert it to per units system.

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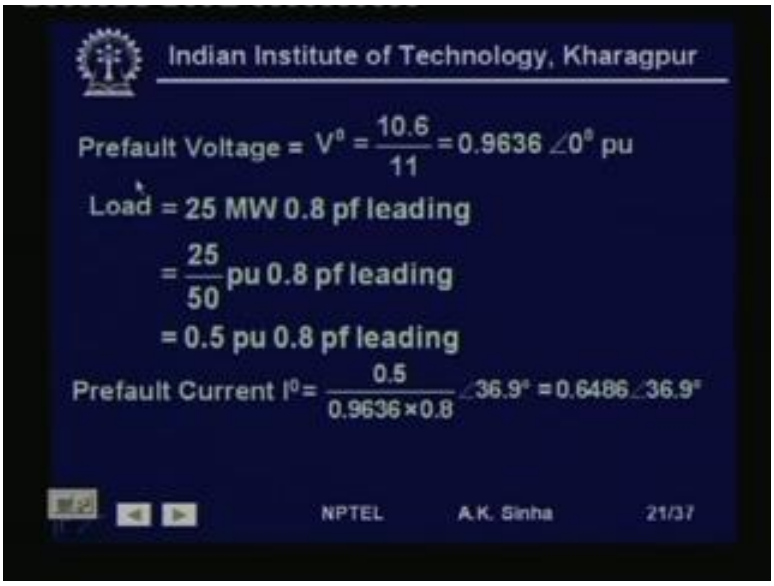

So, we have here the pre-fault voltage V 0 is equal to 10.6 by 11. That is equal to 0.9636, we are assuming this as the reference voltage. So, this angle we have taken a 0 degree. Now, load is given as 25 Mega Watt 0.8 power factor lagging. This is equal to 25 by 50 per unit at 0.8 power factor lagging or 0.5 per unit at 0.8 power factors leading, sorry it should be leading.

So, pre-fault current that is the load current is equal to how much. This is what we say as i 0 is the pre-fault current. Now, this current is equal to how much this is the power and this is the power factor. So, 0.5 divided by the voltage that we have here. So, 0.9636 into 0.8 is the power factor of this and the angle is plus 36.9 degrees, this is 0.8 of factor leading. So, angle is positive. So, current will be leading the voltage.

So, this is current coming out to be 0.6486 angle 36.9 degrees. Now, when the fault occurs the circuit becomes like this, at this point P is shorted to the ground. So, here the voltage E m double dash E g double dash will be there and these will be feeding currents like this to the fault. So, the current from this side is I g double dash, from this side is I m double dash and I f double dash is the current flowing into the fault for this system.

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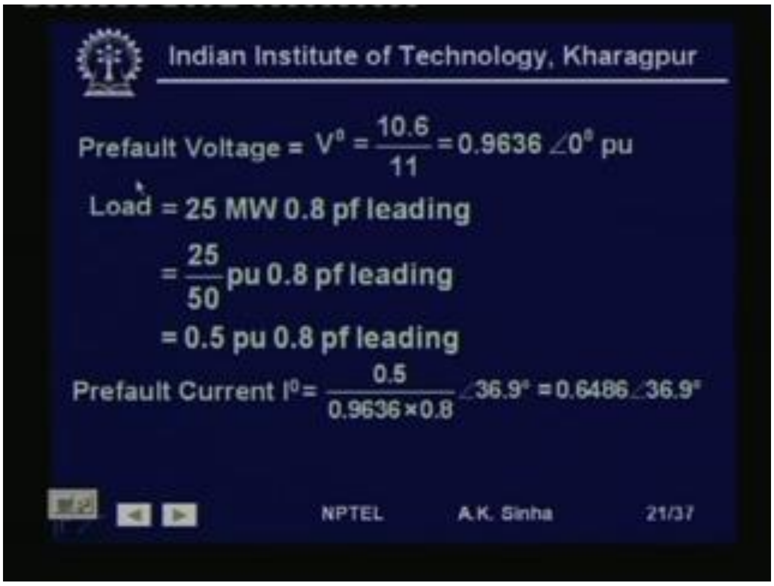

So, what we need to do is first we need to calculate E g double dash. Now, E g double dash as we said is equal to the voltage at this point plus the drop in this.

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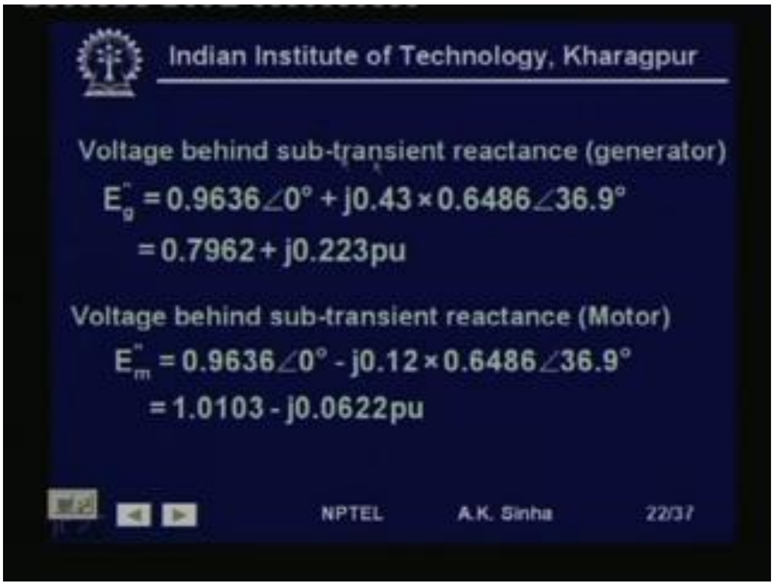

So, this is voltage at this point plus the drop is given by the reactance into the current flowing. So, this is J 0.43 is the total reactance into 0.6486 angle 36.9 degrees. This is the load current, which is flowing. This gives the value of E g double dash as 0.7962 plus j, 0.223 per unit. Now, voltage behind the sub transient reactance of the motor is going to be how much.

Now, if we go back and see this circuit, the current is flowing like this. So, this voltage minus this drop in this reactance is going to be the voltage here. So, voltage behind sub transient reactance for the motor is this voltage 0.9636 angle 0 degree minus j 0.12 into the current flowing. This comes out to be 1.0103 minus j 0.0622 per unit.

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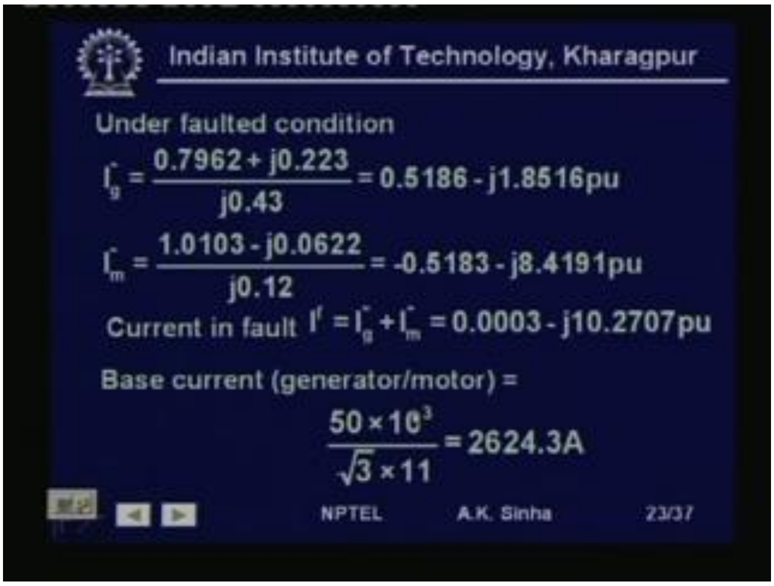

So, once we have calculated these sub transient voltages, behind the reactances, for the generator and the motor. We can calculate the currents very easily, this voltage divided by the reactance. That is, if we see this circuit, this is the voltage and this is the reactance coming into picture. Because this point is now shorted here, so this voltage divides by this reactance. That is E g double dash by the J 0.43 is giving us I g double dash and E m double dash divide divided by J 0.12 is going to give us I m double dash.

So, we can calculate I g double dash like this, comes out to be 0.5186 minus J 1.8516 per unit and I m double dash similarly comes out to be minus 0.5183 minus j, 8.4191 per unit. And the fault current is going to be I g double dash, plus I m double dash, this comes out to be 0.003 minus j, 10.2707 per unit. Now, if we want we can compute the currents in amperes by finding out the base current. So, this is 15 to 10 to power 3 divided the root 3 into 11. This comes out to be 26.24, 0.3 amperes.

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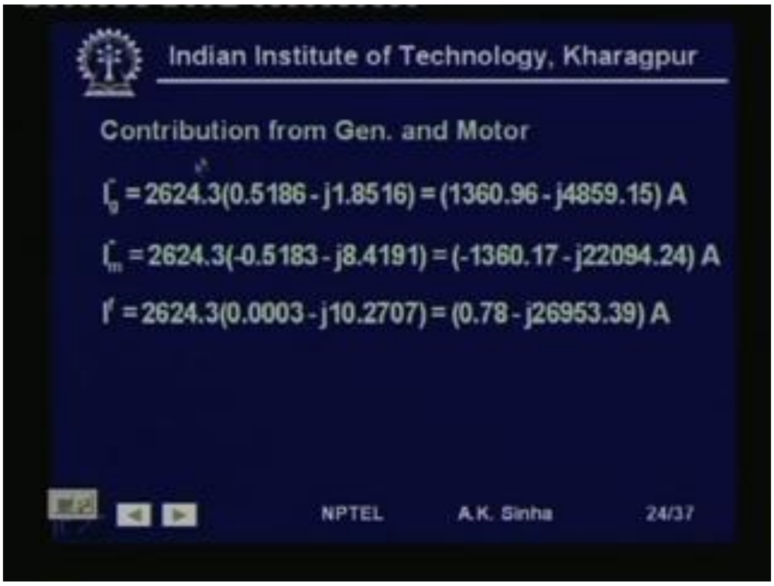

And by multiplying it with the base current, we get the current in amperes for I g, I m and I f, this how we can calculate the short circuit for this small system.

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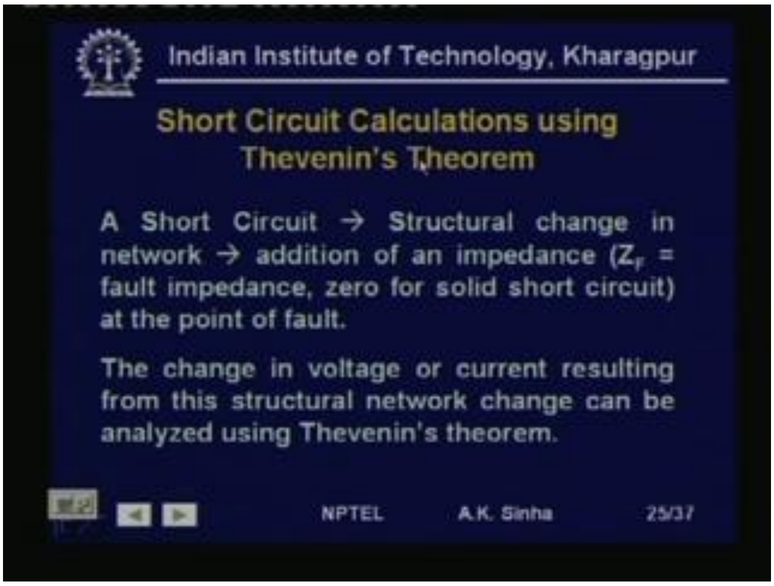

Now, for larger systems, we have to go for a systematic way of doing this and Thevenin's theorem provides an easy way for doing it systematically. So, how do we apply this? If we look at this circuit, what we are seeing is, a short circuit is similar to a structural change in the network, what is the structural change, which is occurring in the network.

If we see here, what we have done is the network, before fault is like this and after fault what we have done is, we have put impedance here, this is a dead short circuit. So, we have a 0 impedance connected at this point. If the fault has some impedance, then we would have put z f here. So, this is like adding impedance at the point of the fault. So, this is, what we are looking at structural change in the network, which is similar to addition of an impedance Z f, the fault impedance 0, for a solid short circuit at the point of fault.

So, this is the change which we are doing in the structure of the network. Now, because of this change in a structure the change in voltage or current, resulting from this structural network change can be analyzed using the Thevenin's theorem.

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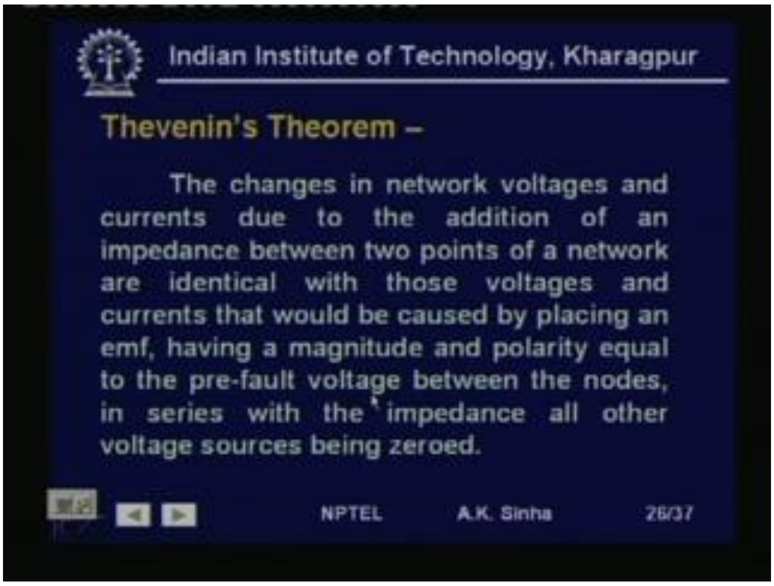

Now, what does the Thevenin's theorem tell us, here we have put it in a form, which is useful to us. The changes in network voltages in the network voltages and currents, due to the addition of a impedance between two points of a network are identical with those voltages and currents, that would be caused by placing an e m f. So, what it is saying, that the changes caused by this addition of impedance, between two points of a network is identical with those voltages and currents.

That would be caused by placing an e m f, having a magnitude and polarity equal to the pre-fault voltage between the nodes. In series, with the impedance with all other voltage sources being 0, now we will see how this happens.

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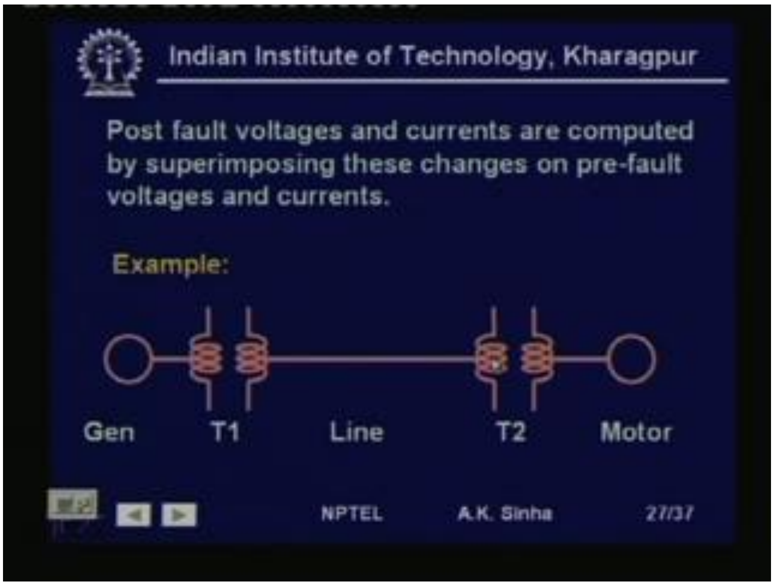

Now, this is let us taking this example, once we calculate these changes by Thevenin's theorem. The post fault voltages and currents can be computed by superimposing these changes on the pre-fault voltages and currents. So, let us take this example, again the same example, that we had taken earlier. Now, the circuit as we had shown earlier was like this. This is the point where the fault is has occurred and this is the voltage V 0 which is the pre-fault voltage at this point.

So, now, we can create a short circuit at this point by putting another voltage of the same magnitude, but with opposite polarity. That is this was the voltage V 0 at this point. The voltage was V 0 at this point, which could be replaced by a voltage source here with V 0 with positive on this side and negative for this lower side.

So, this is what we had earlier, now what we have done is, to create a short circuit, we have added the voltage with equal magnitude. But, opposite polarity to this, then what happens the voltage between these two points become 0.

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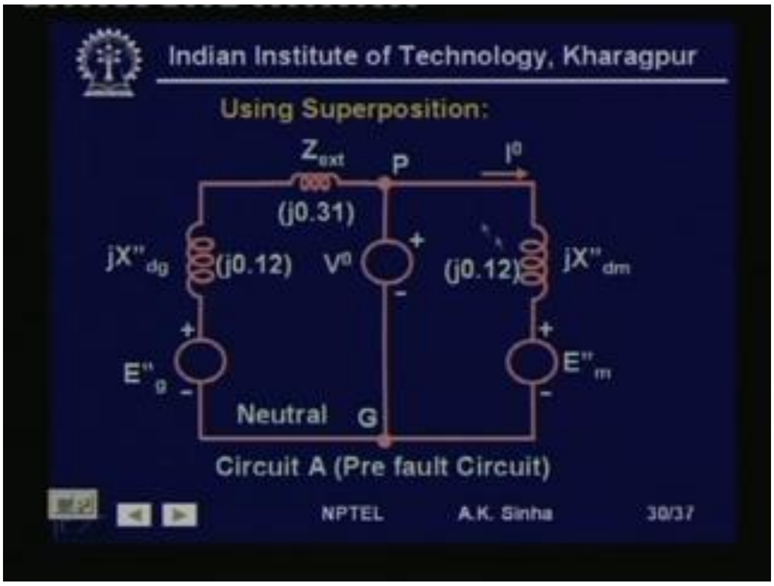

So, this is, how we have created the short circuit. Now, we can use superposition theorem. What we can do is, we can consider this part, where we have neglected this part of the voltage, the other 3 voltage sources are shown here. This is a condition, which is similar to the pre-fault condition. And super post on that, we have this circuit, where this is the voltage source, which we had not taken in the previews case in the circle.

Now, if we look at this what we have, we have two circuits. One was the pre-fault circuit and another was this circuit and these two circuit is put together provide us this conditions during fault. So, the pre-fault circuit plus this circuit and that means, this circuit is giving us the changes in the system, because of the short circuit. So, here, if we see, this is the pre-fault voltage, that we have added between the points for this circuit. And this is what the Thevenin's theorem says. So, this is giving as the changes, this circuit will give us the changes.

So, again pre-fault voltage we have calculated. Now, we can calculate the changes in from the generators side and the motor side with this circuit. So, we can calculate this current, this current together using V 0 by the impedance in this side and V 0 by the impedance on this side. And we will get the total current, which will be the pre-fault current plus the change current from I g side.

Similarly, the total current from the motor side as minus I 0. Because, we are showing the current flowing in the in this direction, therefore we have minus i 0 plus delta I m dash. So, this shows this value and this is the same value. That we had got in the earlier case.

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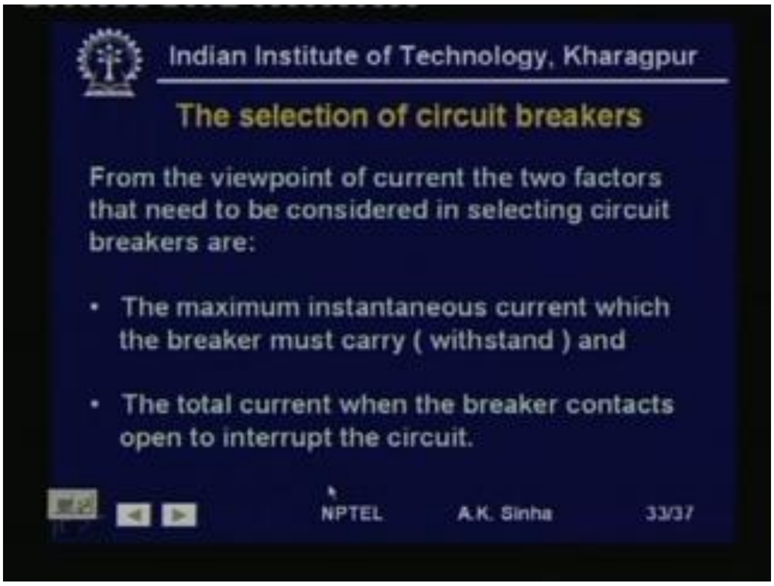

Now, what do we do with this short circuit current that we have calculated? Will, we use it for the selection of circuit breakers. Now, which are used to interrupt these faults is isolate these faults from the circuit or the network. From the point of view of current, the two factors that need to be considered in selecting circuit breakers. That is the two most important factors are that is the maximum instantaneous current, which the breaker must carry, this is the current, which instantaneously flows as soon as the fault occurs. And the second important factor is what is the current, which the circuit breaker is finally going to interrupt, this current is somewhat lower, because the circuit breaker takes some time to interrupt this current.

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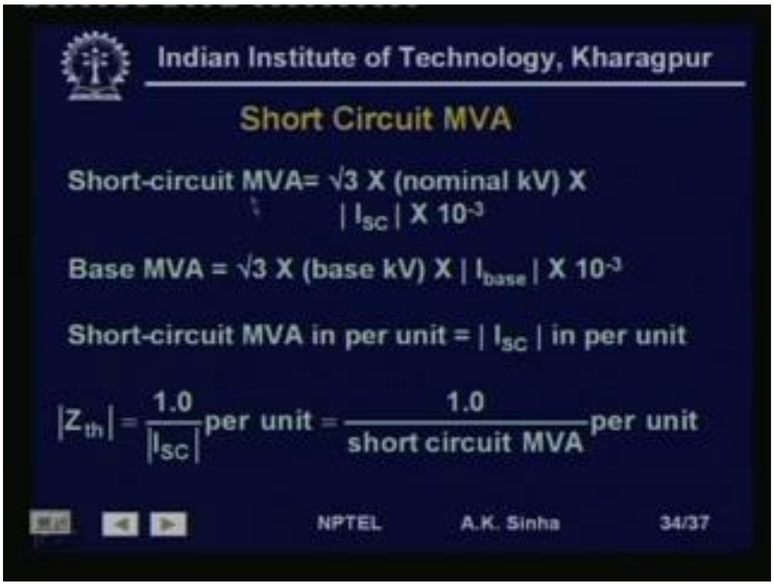

Now, since at the time of the fault, the voltage is much lower and the current is much high, it is found that for circuit breaker ratings. The product of the voltage and the current is more or less constant for the circuit breaker interruption rating. Therefore, most of the time, the circuit breaker manufactures provide a short circuit MVA rating. For the circuit breaker, we define the short circuit MVA rating as root 3 times the nominal kV into the short circuit current in kilo amperes.

So, if we writing this in kilo amperes we have this and then base MVA we write as root 3 into base kV into I base into in 10 to the power minus 3 to take care of the kilo amperes. So, short circuit MVA in per unit will be equal to short circuit MVA divided by the base MVA, this comes out to be equal to I s c in per unit.

Now, if we look at the Thevenin's equivalent circuit, then and the voltage per unit as we have assumed it to be 1 per unit. Then, we will get the Thevenin's impedance as the voltage divided by the short circuit current. So, Thevenin's impedance at the short circuit time is 1 divided by I s c, which is equal to 1 by short circuit MVA in per unit.

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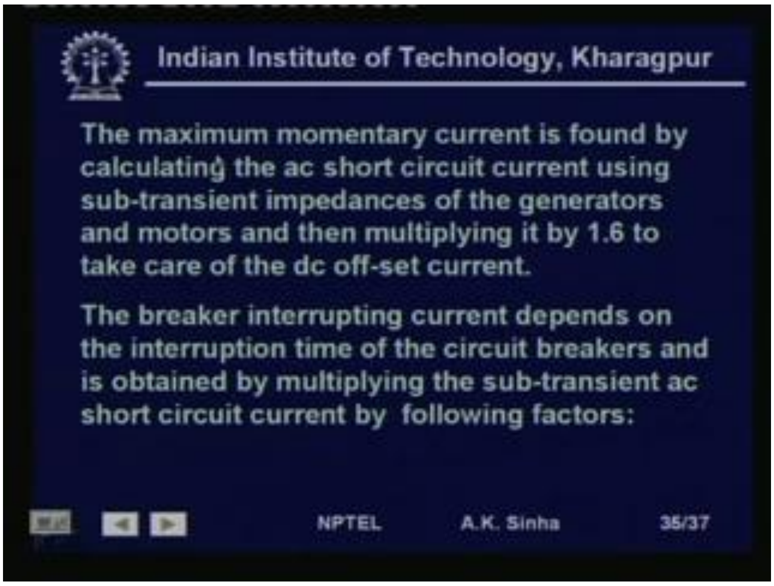

Now, the maximum momentary current is found by calculating a c short circuit current, using sub transient impedance. That is instantaneous fault current, we are talking about. So, we use sub transient impedance and to take care of the d c off-set current, we multiply it by 1.6 times. Now, the breaker interrupting current is depends on the interruption time, which can vary from two cycles to 8 cycles. Because, it takes care relay operating time as well as circuit breaker interruption time.

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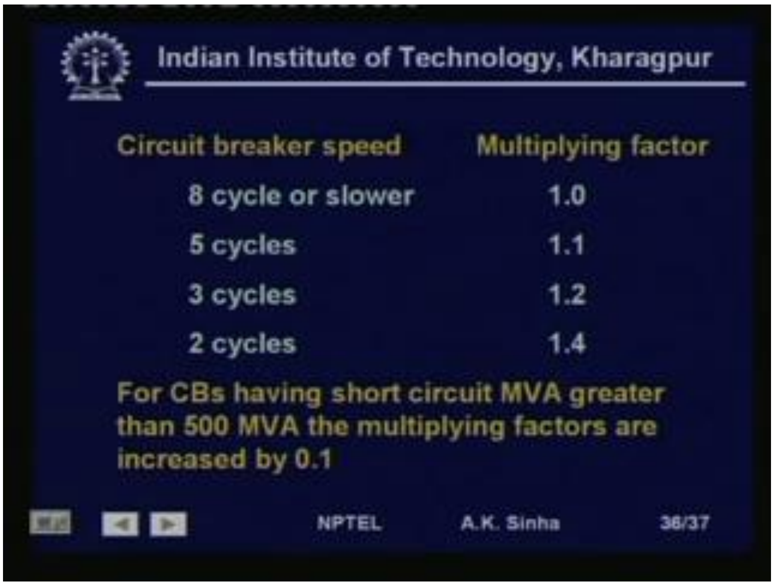

So, we take care of this by using a multiplying factor, which we use like this 8 cycles or slower 1, 5 cycles 1.1, 3 cycles 1.2, 2 cycles 1.4. For circuit breakers, having rating more than 500 MVA, we add 0.1 to these factors.